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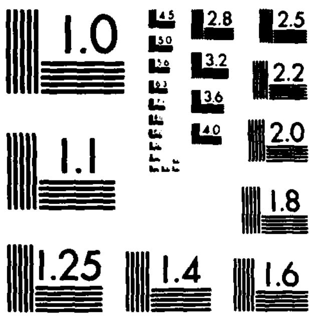
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United States Army Corps of Engineers
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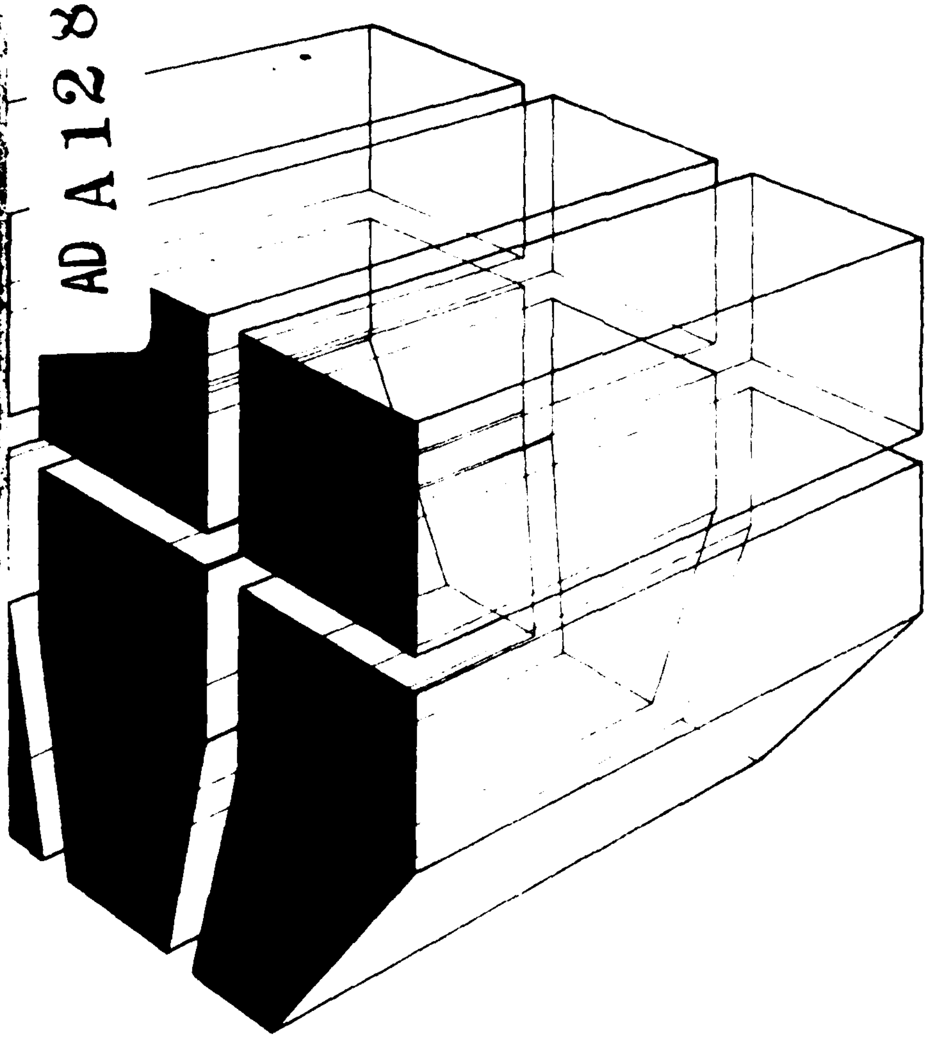
Technical Report N-146
April 1983

Water Conservation and Reuse Guidelines

AD A128516

WATER CONSERVATION METHODS FOR U.S. ARMY INSTALLATIONS: VOLUME II, IRRIGATION MANAGEMENT



by
R. J. Scholze
L. J. Benson
M. A. Kamiya
M. J. Staub
J. T. Bandy

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The objective of this report was to provide guidance that facilities engineers can use to identify practices that conserve water for irrigation and that are appropriate for the Army. To do this, the U.S. Army Construction Engineering Research Laboratory (CERL) examined irrigation practices, defined considerations to be used in developing an irrigation program, and evaluated irrigation systems that conserve water.

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CERL's work indicates that the following guidelines can help conserve water:

1. Water conservation should be considered as part of the installation's energy conservation program,

2. Water conservation techniques, such as installing devices on household fixtures, are an important part of comprehensive water supply planning, and should be considered for retrofitting and for new construction projects,

3. Because many types of conservation devices are available, the facilities engineer can select proven device technology with which there is little risk of failure or public rejection. The transition from conventional fixtures to water conservation devices usually can be made without major behavior changes by residents, AND

4. To reduce the amount of water used for irrigation, turfgrasses with high tolerances to local environmental conditions should be selected when natural landscaping is not applicable.

5. Innovative irrigation methods such as drip irrigation, wastewater reuse, and automatic control of watering should be considered when new irrigation systems are installed or existing systems are upgraded.

6. Irrigation equipment should receive regular maintenance to insure satisfactory service and to prevent the waste of water.

These guidelines are applicable at installations inside and outside the Continental United States under both peacetime and mobilization conditions.

Volume I of this report provides guidance on identifying practices that conserve water in residences.

FOREWORD

This study was performed by the Environmental Division (EN), U.S. Army Construction Engineering Research Laboratory (CERL) for the Assistant Chief of Engineers, under Project 4A762720A896, "Environmental Quality Technology"; Technical Area A, "Installation Environmental Management Strategy"; Work Unit 031, "Water Conservation and Reuse Guidelines." The applicable QCR is 6.27.20A. The OCE Technical Monitor was Walter Medding, DAEN-ECE-D. Dr. R. K. Jain is Chief of EN.

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COL Louis J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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WATER CONSERVATION METHODS FOR U.S. ARMY INSTALLATIONS: VOLUME II, IRRIGATION MANAGEMENT

1 INTRODUCTION

Background

Turf maintenance accounts for a large part of the more than 130 billion gallons of water the U.S. Army uses annually. Irrigation for lawn and turf maintenance, for example, takes as much as half the water used during warm months and is responsible for a correspondingly high proportion of operation and maintenance costs. There are techniques which permit adequate turf maintenance with much less water than is now applied. The potential water savings could be critical at installations that are subject to drought or that have very limited water supplies and a mobilization mission calling for substantially increased populations.

Objective

The objective of this volume is to provide guidance that facilities engineers can use to identify practices that conserve water for irrigation and that are appropriate for the Army.

Approach

To accomplish the objective, CERL examined irrigation practices, defined considerations to be used in developing an irrigation program and evaluated irrigation systems that conserve water.

2 IRRIGATION PRINCIPLES

This chapter discusses the purpose of irrigation; the relationships between soil, water, and plants; factors affecting the amount of water needed by plants; and methods of calculating the amount of water needed for irrigation.

The primary purpose of irrigation is to provide a soil environment conducive to seed germination, root system development, seedling emergence, and plant growth. Plant roots should be able to absorb water at a rate comparable to transpiration losses.* Soluble salts in the root zone must not limit plant growth or water absorption. Other considerations include maintaining adequate soil aeration, providing a favorable soil temperature range for better quality plants, and preventing drought injury to young seedlings.

To design and operate a sprinkler irrigation system effectively, one must know: (1) the seasonal and peak irrigation water requirements for turfgrass or ground covers; (2) the plants' total water requirements, which are based on seasonal evapotranspiration water needs; and (3) the variations in water use through the growing season.

Irrigation requirements during establishment of turf are discussed in TM 5-630. Irrigation may also be needed to establish ground covers, vines, shrubs, and trees; rain cannot be depended on. New plantings should be inspected regularly for proper watering, weeding, pruning, cultivation, fertilization, control of disease and insects, and protection from vertebrate damage. Immediately after planting, a lack of water could be fatal; the reduced root system might not supply enough moisture to the top of a plant.

Usually, plants must be watered periodically for at least 1 year. Irrigation or watering should be done slowly and thoroughly, approaching field capacity without runoff. This will develop deep roots for better drought survival and earlier establishment. Plants must be irrigated frequently and thoroughly so that their root zones are always moist.

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* The following definitions may be helpful in understanding the irrigation principles discussed in this chapter. Transpiration is evaporation of water to the atmosphere directly from plant surfaces, or to intercellular spaces and then, by diffusion through stomata, to the atmosphere. The stomata in grasses transpire about 90 percent of the water taken in; only about 2 percent is used in metabolism. Evapotranspiration is the sum of transpiration plus water evaporated from the soil or exterior parts of the plant. Units are often in inches or feet. This is the basic factor determining irrigation water requirements. The irrigation water requirement is the amount of water, excluding precipitation, needed to maintain correct soil moisture and salinity levels. This requirement is expressed in units of depth per time — i.e., inches per month.

Soil-Water-Plant Relationships

Physical Properties of Soil

Soil Profile. Soil contains vertical layers called horizons; their arrangement makes up the soil profile. The surface layer, called the "A" horizon, contains most life forms and is the layer normally cultivated for crops. Next vertically is the "B" horizon, which may be heavier and may have accumulated clay. The "A" and "B" horizons are considered the true soil. The "C" horizon consists of the unweathered parent material. Different conditions create different profiles; some horizons may not be present. Examples of irrigated soil profiles are shown in Figure 1, which indicates a wide range of variations and texture.

Texture. The fine distinctions within the soil horizons are called soil texture. This is the relative proportion of each mineral particle size classification: sand, sandy loam, loam, silt loam, clay loam, and clay. The U.S. Department of Agriculture defines soil separates as follows (sizes in millimeters): very coarse sand, 2.0 to 1.0; coarse sand, 1.0 to 0.50; medium sand, 0.50 to 0.25; fine sand, 0.25 to 0.10; very fine sand, 0.10 to 0.05; silt, 0.05 to 0.002; and clay, below 0.002.[1]

Soil class may also be determined from particle size (Figure 2). After a mechanical analysis such as sieving, the diagram can help determine soil class based on the relative proportions of sand, silt, and clay. A percentage range from 0 to 100 is distributed along one side of the triangle for each component. After the appropriate percentage has been located along each side, a line is traced at a 60-degree angle toward the center. The name of the soil texture is where the three lines intersect.

Appendix A presents a simple test that can give a general idea of soil characteristics. A commercial soils engineering firm, Government extension service office, or similar agency can provide more complete soil evaluations.

The texture helps indicate soil characteristics such as aeration, drainage, water retention, and fertility. For example, sand particles, the largest mineral particles, fit together so that there are large pore spaces. This means that sandy soils have the least surface area per volume of material; therefore, they drain rapidly and hold little water.

Soil Structure. Soil structure is the way individual particle sizes clump together into aggregates. Determined by the sizes and shapes of these groups and their resistance to breaking down, structure influences the movement of water and air through the soil, thus affecting productivity. Ease of root penetration, water intake rate, and erosion resistance are also affected. Structure can be identified by the shape, arrangement, and size of aggregates.

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[1] "Soil-Plant-Water Relationships," National Engineering Handbook Irrigation, Section 15, Chapter 1 (U.S. Department of Agriculture, Soil Conservation Service, 1964).

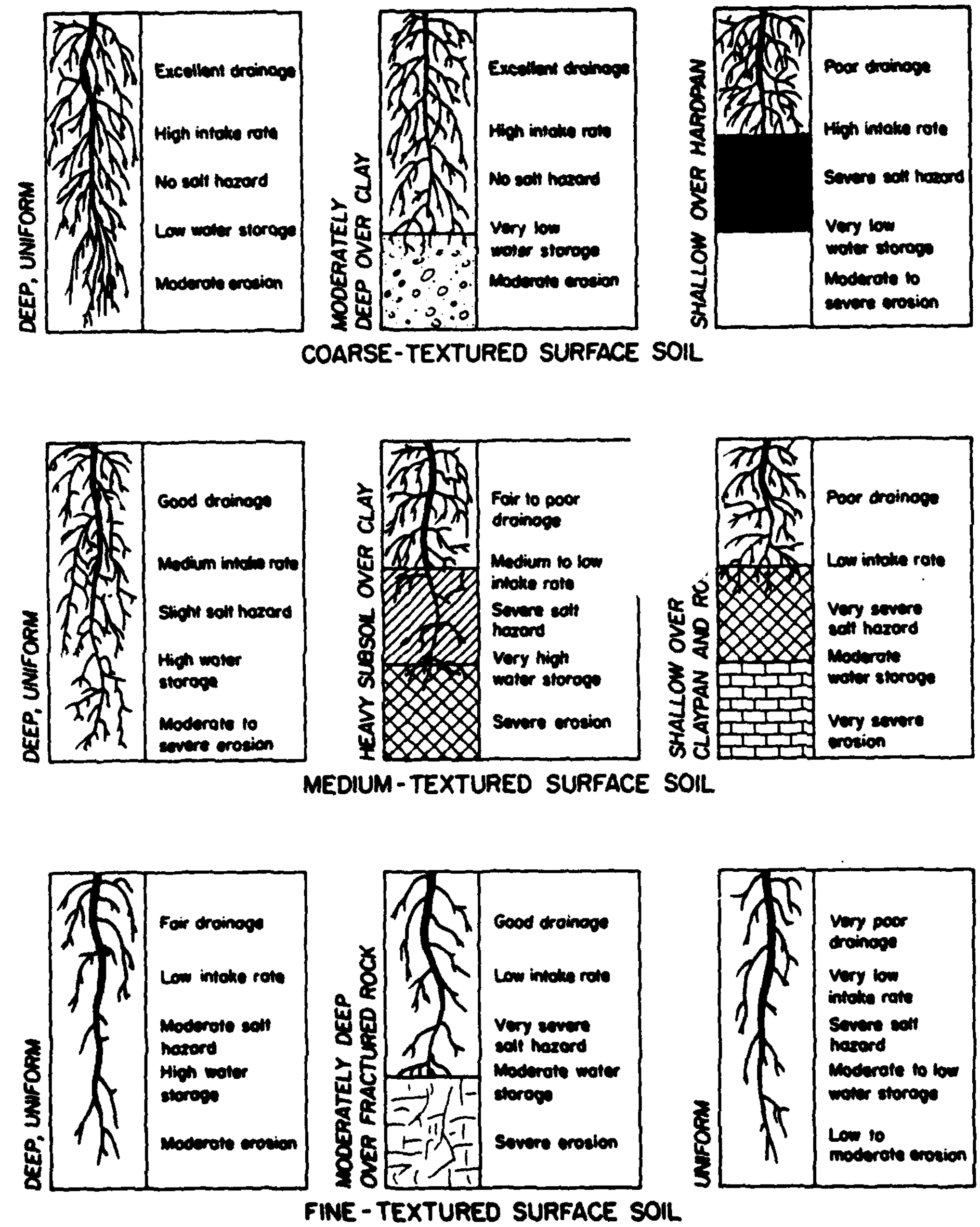

Figure 1. Some typical irrigated soil profiles. (From "Conservation Irrigation," Information Bulletin No. 8, [U.S. Department of Agriculture].)

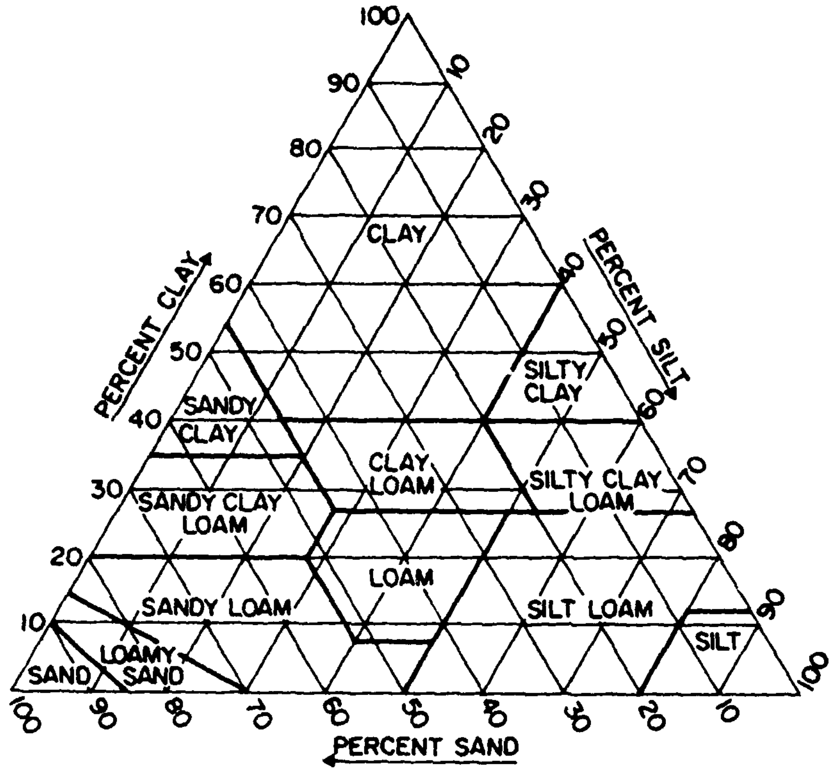

Figure 2. Proportions of sand, silt, and clay for different soil textures. (From Soil Survey Manual, USDA Handbook 18 [U.S. Department of Agriculture, 1951].)

Soil structural forms are presented in Figure 3; granular and crumb structures are the most desirable for plants. Structure can be checked quickly by examining a handful of dry soil which has been crushed between the fingers. The shape of the aggregates should be visible to the naked eye. Heavy compaction of wet soil will destroy soil structure.

Soil Organic Matter. Soil organic matter is important to turfgrass and ground cover growth. This organic material affects soil structure, aeration, water retention, water movements, and nutrient availability. Relative proportions of the organic and mineral components determine the character of the soil. Loam, for example, is a mixture of sand, silt, or clay, with some organic matter called humus. Fresh organic matter keeps soil open and spongy, allowing free movement of water and air. Organic material also holds water in the soil; this provides more available water capacity. Beard[2] presents a soil classification system based on organic content:

Mineral soils: 1 to 8 percent organic matter by weight
Organic soils: >20 percent in upper 1 ft of soil profile
Peat soil: Undecomposed or slightly decomposed organic matter
Muck soil: Well decomposed organic matter

[2] J. B. Beard, Turfgrass Science and Culture (Prentice-Hall, 1973), p 329.

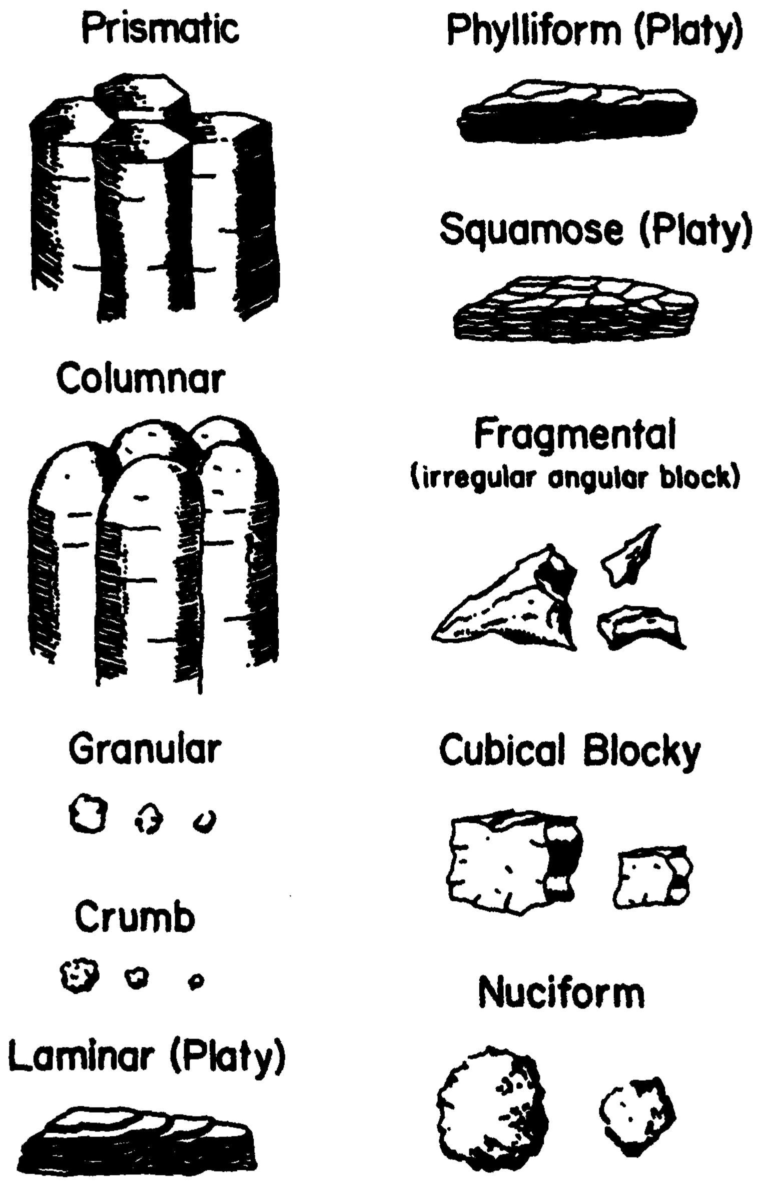

Figure 3. Soil structural forms.
(From C. H. Pair, et al., <u>Sprinkler Irrigation</u> [The Irrigation Association, 1975], p 51.)

Porosity. Porosity refers to the percentage of soil occupied by water or air instead of soil particles. This property indirectly describes the soil's capability to transport water. Porosity is influenced by both the texture and structure of the soil. Coarse textured sandy and gravelly soils have the smallest pore space; fine textured clay loams and clays have greater space. Particles of uniform size have comparatively large spaces between them. When particles vary greatly in size, the soils become more closely packed and have smaller pore space. With proper care, finer-grained soils act as groups of particles or granules, while in coarser textured soils each particle is separate.

Infiltration and Percolation Rates. The infiltration or intake rate is the soil's capability to take in water during irrigation. This characteristic must be considered when an irrigation system is being planned. The intake rate is affected by the soil's surface conditions and physical characteristics. After infiltration, the water moves downward through the soil; this is called percolation. Appendix B describes infiltration and percolation tests. Figure 4 indicates intake rates of different soils along with available water holding capacity.

The infiltration rate primarily depends on soil management and the number of large pores at the soil's surface. Keeping the surface open and porous will maintain a high capacity. Salts and compaction by heavy use can dramatically reduce porosity and the infiltration rate; aeration and loosening of

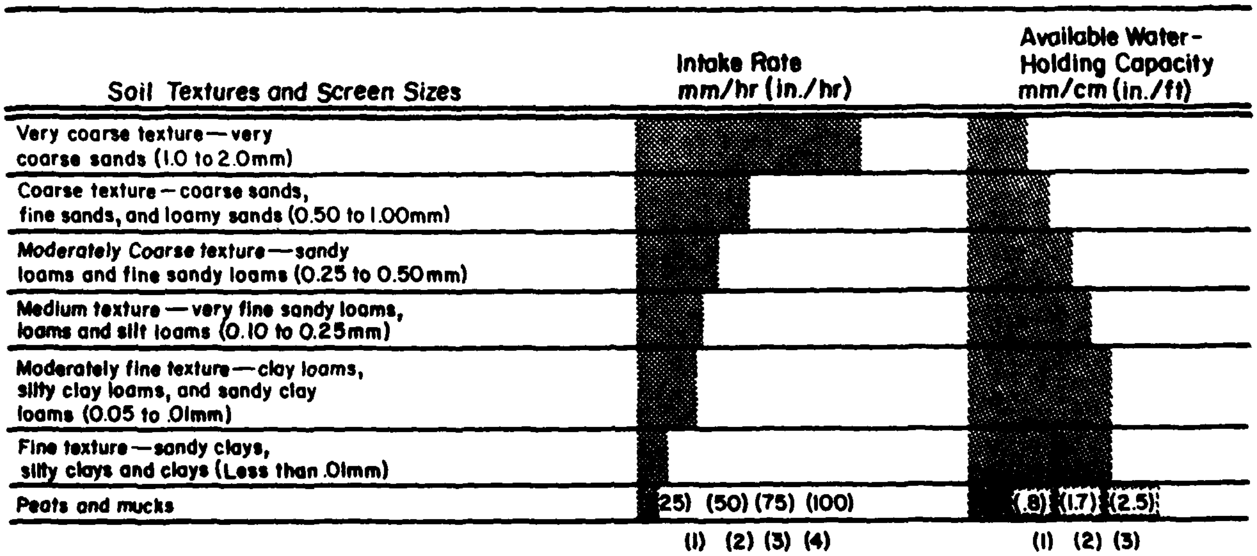

Figure 4. Intake and available water-holding capacities of soils with different textures.
(From J. H. Turner and E. L. Anderson, Planning for an Irrigation System [American Association for Vocational Instructional Materials, 1980], p 47.)

compacted soil increase water intake. Mulching can prevent raindrop impact from sealing the surface. Other factors affecting intake rate include the presence or absence of cover crops, tillage practices, amount of organic matter, soil temperature, soil slope, time, crop rotation, irrigation water quality, presence of hard pan, initial soil moisture content, and height of water table.

Water Holding Capacity. The water holding capacity or field capacity of soil is the amount of water it will hold after the free water has been drained away by gravity. Moisture content is measured at a specified time after a thorough wetting. While drainage does not stop, it may become very slow. Water holding capacity determines the amount of irrigation needed for good plant growth. Water holding capacity primarily depends on soil texture. Coarse-textured soils hold less than fine-textured soils (Figure 4).

All the water held by soil is not available to plants. After irrigation, plant roots remove available water; the remaining water is more tightly bound to the soil and is less available to plants. For example, high-clay-content, fine-textured soils hold large amounts of water, but much of it too tightly to be used by plants. Silt loam soils with a good balance of sand, silt, and clay usually have the highest available water holding capacity. Mulch and organic matter may be used to increase water holding capacity.

Soil moisture content can be found in several ways. The standard approach is to measure the weight difference between wet and oven-dried field samples. Tensiometers and electrical resistance blocks are also used.

A basic principle of turfgrass irrigation is that the soil's water content must readily satisfy plants' water absorption requirements without creating internal stress. A lack of oxygen or an accumulation of toxic gases can seriously injure plants that have been saturated for a long time.

Topography. The topography of an irrigated surface becomes important when control of erosion and surface runoff is considered. The surface should be smooth and free of low spots so that water does not stand in puddles or ponds. Surface irrigation is easiest on flat or gently sloping soil with recommended maximum grades of 8 and 14 percent, respectively, for lawns and wooded areas.[3]

Basic Requirements for Good Soil or Root Zone Conditions

Some basic requirements for good soil or root zone conditions include adequate soil nutrients, a pH level between 5.5 and 8.3, proper grading or land slope, adequate moisture applied at the correct rate, proper density, and sufficient air spaces. The chances for establishing a healthy landscape will improve if any of these requirements are met.

[3] Murray Milne, Residential Water Reuse, Report No. 46 (California Water Resources Center, September 1979), p 144.

Resistance and Tolerance

Plants that resist drought can help save water because they do not need frequent irrigation. Table 1 presents the relative drought resistance of different turfgrasses.

Cultural Requirements

Irrigation intensity depends on several factors. Temperatures interact with moisture to determine the amount ot water needed for a given area. More water is lost by evaporation and transpiration during hot, dry periods than on cool, foggy days. Wind also increases water requirements. The amount of water needed for irrigation is affected not only by the environment, but also by plant species. Therefore, the availability of water should be an important consideration when plants are chosen.

Table 1

The Relative Drought Resistance of 22 Turfgrasses
(From James B. Beard, TURFGRASS: Science and Culture, (c) 1973, p 291. Reprinted by permission of Prentice-Hall, Inc., Englewood Cliffs, NJ.)

Drought resistance	Turfgrass species
Excellent	Buffalograss
	Bermudagrass
	Zoysiagrass
	Bahiagrass
Good	Crested wheatgrass
	Hard fescue
	Sheep fescue
	Tall fescue
	Red fescue
Medium	Kentucky bluegrass
	Redtop
	Timothy
	Canada bluegrass
Fair	Perrenial ryegrass
	Meadow fescue
	St. Augustinegrass
Poor	Centipedegrass
	Carpetgrass
	Italian ryegrass
	Creeping bentgrass
	Rough bluegrass
	Velvet bentgrass

Landscape Designs

Landscape designers should consider the advantages of keeping existing vegetation and using native plant species. For example, leaving this vegetation may prevent serious erosion and dust problems while preserving natural shade and an acceptable appearance. Saving trees is far cheaper than removing them. The length of time needed to re-establish trees, shrubs, ground cover, and turf may make preservation advantageous.

Site construction activities such as clearing and grading should be minimized. Minor changes in walk and road layout may be needed to save vegetation; these adjustments should be made during early construction.

Landscape materials may influence irrigation practices and water requirements. For any new landscaping, plants which need less irrigation and maintenance should be selected.

Use of turf and ground covers may not always be the best solution; sometimes landscape use of stone may be adequate. In some areas, it might be better not to landscape at all.

It is important to manage a landscape and maintenance program economically. Several factors must be considered to achieve the best possible results. Long- and short-term costs for operation and maintenance, capital costs of equipment and materials, use of resources such as water and energy, and landscape appearance and function must correspond with the philosophy and budget of the installation.

Factors Affecting Plant Water Requirements

The water requirements of plants depend on physical and climatic factors, soil, and chemical treatments. Plants have evolved so that their leaves are designed for photosynthesis rather than efficient water use. Leaves ordinarily are flat, wide, and exposed to sunlight. In addition, leaves transpire water to keep the sap stream moving. This effectively transports nutrients hundreds of feet. Another benefit of transpiration is that it cools the leaves; protoplasm will not function or survive much past 100°F. Transpiration draws heat from leaves when the change to vapor occurs. The plant's stage ot growth will change transpiration rates during the season, although evaporation demand is constant. Physical attributes of plants include an impervious waxy cuticle to protect against drying out. Dry habitat has caused plants to evolve coping mechanisms such as photosynthesis through green stems, water-storing organs, and stomata in areas with less exposure.

Solar radiation is the climatic factor affecting plant water requirements most. It supplies the energy needed to transfer water from a liquid to a vapor in soil and plants. Other influences on plant water requirements are rainfall, humidity, wind, and temperature of soil and air.

Soil factors contributing to plant water requirements include concentration of salts, soil temperature, and available water in the root zone. Salts increase irrigation requirements, force plants to work harder to obtain water, and are lethal in high amounts. Soil temperature influences vapor pressure,

water viscosity in the soil, and the capacity of roots to absorb water. Available water -- which determines how hard a plant must work to fulfill its water needs -- depends very much on soil structure and texture.

Chemical treatments can reduce transpiration; they have also been used on evergreens to prevent winterburn. These preparations usually stimulate the stomata to close by clogging or covering. For example, phenyl mercuric acetate is used to keep golf course greens from wilting. These antitranspirants or antidesiccants have had little success in arid climates, but do work well in the eastern and midwestern states. The directions for use must be followed carefully; the chemicals must be applied at the proper temperatures.

Several compounds can increase infiltration and soil drainage, and can even modify the structure of water-repellant soils. These compounds -- commonly called wetting agents, surfactants, and surface-active agents -- have also increased the yields of some plants and had toxic effects on others. Chemically, these agents can be anionic, cationic, or nonionic; they are organic compounds with one or more hydrophobic groups. These compounds reduce the surface tension of water, which is then absorbed more readily by the soil. Civilians have used the nonionic surfactants most often for turfgrass. The Army rarely uses wetting agents. However, one installation has applied herbicides with wetting agents; the results have been positive. The effectiveness of commercial products depends on soil and plant conditions. Currently, wetting agents are expensive and have few applications. But these compounds warrant further investigation because of their potential benefits. Testing on small areas should precede general use at an installation.

Irrigation Water Requirements

Often, grass does not get the proper amount of rain at the right time. An irrigation system needs enough water to insure turf maintenance during the most severe drought. Therefore, total water requirements must be determined precisely.

First, the amount of water required per week should be calculated. This figure can vary widely because of turf type, soil type and condition, and other factors; as a rule, grass needs at least 1/2 to 1 in. of water per week. Less than this during some seasons may be acceptable in humid regions where water is used to maintain a presentable appearance rather than to insure survival. Then, the available soil moisture and the amount of moisture should be measured, and the water demand should be estimated.

Before drying out, turf loses its resiliency; footprints remain outlined for a long time; other symptoms are a bluish cast and reduced growth. A watering program should begin when turf exhibits these characteristics.

Available Soil Mositure

Measurements of soil moisture's availability indicate the strength of the pressure holding moisture around soil particles.* Plants need to overcome

* For these measurements, contact the agricultural department of a local college or university, or the county agricultural extension agent.

this pressure so the roots can extract water from the soil. Available water is the range of soil moisture between field capacity and wilting point, the amount of pressure a plant's root system exerts. Wilting is usually considered permanent at about 15 atmospheres, but this varies with the plant species. Permanent wilting also varies according to soil type -- from around 10 atmospheres of pressure for silty clay soil to 20 atmospheres for fine sandy soil. Field capacity generally has a soil water tension of about 1/3 atmosphere, which provides the most favorable conditions for growth. This tension, which is based on the amount of energy plant roots need to absorb moisture, increases rapidly as the limiting force is approached.

Since soils differ in their capacity to hold water, the amount of water needed to go from wilting point to field capacity varies. For example, silt and clay hold more water than sand does; thus, sandy soil needs more water to move from the wilting point to field capacity. The available water capacity is usually expressed as the number of inches of water needed to bring a layer of soil 1 ft deep from the wilting point to field capacity.

Testing Soil Moisture

In addition to measuring moisture availability, one must decide whether irrigation is needed. This can be done in several ways. For example, the condition of plants can be observed. To check the amount of water in the soil, one can use soil-feel tests, moisture budgets, tensiometer measurements, and other procedures. The approaches described below are common; tensiometers are particularly useful with automatic irrigation systems.

One can often see that plants need watering; symptoms include wilting leaves, changes in leaf appearance, and heavy leaf fall or death of young leaves. Footprints can be seen for some time in turf that needs to be watered.

For the soil hand-feel test, a shovel or soil sampling tube is used to collect soil samples at various depths and from several places in the irrigated area. A small soil sample is rolled by hand into a ball. If no ball can be formed, the soil is probably too dry to supply water to the plants. If the ball crumbles after being rubbed with one's thumb, the soil's moisture is appropriate. If it does not crumble, the soil is probably too wet.

Moisture budgets estimate the amount of water in soil; these budgets are based on the ratio of measured weather elements to plant's water consumption. Evaporation is the measurement often used. For a budget to be effective, evaporation must be related to the amount of water consumed by specific crops.

Tensiometers measure the soil's moisture level directly and easily. A tensiometer is a closed tube with a porous ceramic tip at one end and a vacuum gauge or mercury manometer at the other. It is filled with water and installed in the soil with the measuring gauge above ground. As soil dries, it sucks water through the porous tip, creating a partial vacuum which is measured by the gauge. Soil moisture tension is read directly. At each irrigation site, two tensiometers usually are placed beside each other; these penetrate to different depths of the root zone.

Buried porous gypsum blocks are used to test the electrical resistance or conductivity of solutions. Relative tension of the surrounding soil solution controls the moisture content of the blocks, creating changes in resistance. Since resulting electrical resistance or conductance is an indirect measurement of the soil moisture tension, calibration is necessary.

Oven drying soil samples provides units of percent moisture based on the soil's dry weight and volume of water. Since this process takes much time and effort, normally it is not used to decide when irrigation should be scheduled.

A neutron method is available to determine soil moisture with commercially available electronics instruments. The equipment is expensive and must be operated properly.

The carbide method is based on gas produced when moisture is combined with calcium carbide. The gas pressure is indicated on a gauge and converted to percent moisture through an interpretive chart.

Estimating Water Demand

When estimating the water demand for a given area, one must consider many factors -- e.g., type of turf, soil type and texture, and climatic conditions. Moisture demand is also affected by the age or growth stage of plants, use of mulches to reduce soil surface evaporation, efficiency of irrigation methods, and use of water to leach salts from the soil. For a planting with a known rooting depth and a soil with known water penetration attributes, one can estimate the amount of moisture required to wet the soil to a given depth. Plant water requirements must consider the total water used in evapotranspiration, the determining factor when irrigation water requirements are computed.

There is seldom time or money to calculate evapotranspiration rates for a particular plant in a particular locale. Therefore, one must rely on the results of local studies, published results from studies in similar areas, and theoretical estimates. The methods most often used for measuring evapotranspiration are soil sampling, lysimetry, water balance, and energy balance.

Soil sampling is the most common of these. The first set of samples is taken 2 to 4 days after an irrigation, and the second set 5 to 10 days later, or immediately before the next irrigation. Several samples are oven dried at 221°F to measure the soil moisture decrease. The rate of evapotranspiration is calculated with the following equation:

$$ET = \frac{W_{et}}{\Delta t} = -\sum_{0}^{S_r} \frac{(\Delta\Theta \ \ S + R_e - W_d}{\Delta t} \qquad \text{[Eq 1]}$$

where S = distance from the soil surface

S_r = depth of the effective root zone

$\Delta\Theta$ = volumetric change in soil moisture (negative for a decrease)

Δt = time interval between sampling dates (days)

R_e = effective rainfall
W_{et} = water used in evapotranspiration
W_d = water drained from the zero (ground level) to S_r depth.

When gravimetric sampling procedures are used, soil moisture is usually expressed as a percentage on a dry-weight basis, P_w, and must be converted to a volumetric basis by multiplying by the bulk density, s, of the soil:

$$\Theta = s \frac{P_w}{100} \qquad \text{[Eq 2]}$$

Several precautions are necessary: (1) the depth to the water table should be much greater than the root zone depth; (2) at least six sampling sites should be used; (3) there should be little drainage; (4) the active root zone depth should be used; (5) sampling should be done only when there has been light rainfall or none at all. Neutron soil probes have also been used satisfactorily.[4]

Lysimeters or evapotranspirometers are soil-filled tanks in which crops or other plants are grown to measure the amount of water used. Proper construction, installation, and operation will produce reliable data. There are three types ot these devices: (1) nonweighing, constant water table models for areas with a high water table; (2) nonweighing percolation models, which measure changes in the soil's water storage; and (3) weighing models, which are the most accurate over short periods of time.

Water balance techniques are generally used for large areas and long time periods. Annual inflow and outflow or other data are correlated with information such as annual consumption.[5]

For the energy balance method, the general procedure is to determine net radiation, heat absorbed by or released from the soil, and the Bowen ratio. Well-trained personnel and elaborate instrumentation are required.

In regions where no relevant actual data are available, evapotranspiration must be estimated. There are several estimating procedures, including the Blaney-Criddle, Thornthwaite, Penman, Jensen-Haise, and pan evaporation methods. Usually, these are based on the correlation of measured evapotranspiration with one or more climatic factors.

Blaney and Criddle have developed an empirical relationship between evapotranspiration, mean air temperature, and mean percentage of daytime hours. The method was first developed for seasonal use; however, monthly estimates have also been made. The method, its modifications, and tables of coefficients are explained in Pair, et al.[6] This approach can be used in the western United States.

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[4] C. H. Pair, et al., Sprinkler Irrigation (The Irrigation Association, 1975), p 100.
[5] Pair, p 101.
[6] Pair, p 100.

The Thornthwaite method correlates mean monthly air temperature with evapotranspiration as determined by water balance studies of east-central United States valleys with adequate soil moisture. Pair, et al., gives additional information and sources.[7]

Penman has developed a fairly accurate equation which requires more meteorological data than other methods. Net radiation, solar radiation, windspeed, vapor pressure, temperature-related constants, and other values contribute to the accuracy of the equation. Pair, et al. explains further, defines terms, and provides some information in tables.[8]

Jensen and Haise have correlated soil sampling evapotranspiration procedures with solar radiation and mean air temperature in arid and semi-arid areas. Crop coefficients and information about applying the equation are available in Pair, et al.[9]

Pan evaporation may be used to estimate mean peak and total evapotranspiration. To adjust for growth stage and varying crop cover during the growing season, a variable coefficient generally is needed for these estimates. Users of this procedure must understand the following factors: evaporation rates are not identical for pans in the same area; site conditions affect the evaporation rate; coefficients are less reliable for short-term estimates; and pan evaporation does not reflect the influence of decreasing soil moisture. Seasonal evapotranspiration values are higher in arid regions than in humid regions due to amount of solar radiation, humidity, and winds. Pan evaporation is probably the easiest method to use and is reasonably accurate with appropriate coefficients.

The general equation is:

$$ET = C_{et} E \qquad \text{[Eq 3]}$$

ET = evapotranspiration
C_{et} = coefficient relating pan evaporation to evapotranspiration
E = pan evaporation.

These coefficients should be available from the agriculture department of a nearby college or State university. The county agricultural extension service agent may also have information. If pans are not available, the closest United States Weather Bureau (USWB) installation should be able to provide values for pan evaporation. Local colleges may also be helpful. For proper correlation, one must know the type of pan: USWB or Bureau of Plant Industry (BPI). Instructions and equipment for installing pans are available from the USWB.

Most turfgrasses are shallow rooted, (less than 1 ft), and will need more frequent and lighter irrigations. Youngner performed studies comparing tensiometers, evaporation pans, and commercial judgment for determining irrigation frequencies for two different sets of turfgrasses at a Santa Ana, Cali-

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7 Pair, p 105.
8 Pair, pp 105-109.
9 Pair, pp 109-115.

fornia, experiment station.[10] For warm-season grasses, bermuda and St. Augustinegrass, the least amount of water was used with automatic tensiometers. Cool-season turfgrasses, Kentucky bluegrass and tall fescue, received approximately equal amounts of water from each method. Warm-season grasses used less than cool-season grasses, with minor differences between the two species in each category. The author believed this resulted from less efficient water use because of the cool-season grass' shallower root systems. Youngner also concluded that actual water use can be estimated more accurately by evaporation than by Blaney-Criddle calculations.

A study in Arizona showed that water level significantly affects consumptive use.[11] Researchers found that a watering range of 50 to 80 percent of evaporation pan was adequate, depending on the desired balance between lush growth and economical operation of the irrigation system. In addition, it was found that bermuda grass and Zoysia used less water than tall fescue and St. Augustine grass; tall fescue consumed the most and bermuda grass the least.

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[10] V. B. Youngner, Turfgrass Water Use, University of California Studies (University of California, Riverside, n.d.).

[11] W. R. Kneebone, et al., Water Requirements for Urban Lawns, Office of Water Research and Technology Report, Project B-035-WYO (Laramie, WY, 1979).

3 CONSERVING IRRIGATION WATER AT ARMY INSTALLATIONS

The Army has three types of land use areas: improved, semi-improved, and unimproved. Improved grounds must be attractive; they require regular care and mowing, and irrigation for establishing and maintaining turf. There are two kinds of improved areas: lawn-type plantings and recreational areas and parade grounds. Lawn-type plantings include lawns, cemeteries, and adjacent areas receiving moderate foot traffic and requiring moderate care and maintenance. Recreational areas and parade grounds include athletic fields, golf courses, playgrounds, and similar areas of heavy foot traffic. There is frequent irrigation, maintenance, fertilization, and mowing.

The three categories of semi-improved areas include ammunition magazines and embankments; airports, heliports, antenna fields, field training areas, and similar areas, and wildlife food and cover crops. Ground cover is used on semi-improved areas to control dust and erosion. Generally, these areas require little maintenance and irrigation, except during establishment. Crushed rock or other aggregates are often used in areas of low rainfall.

Plantings on unimproved grounds stabilize the soil and control erosion. Care and irrigation are seldom needed.

Seasonal watering of landscaped or turfed areas can consume large quantities of potable water. To emphasize the effect of irrigation, Table 2 presents water usage and costs for one military installation. The table shows how consumption begins rising in April until summer usage is more than twice winter consumption. This rise in water usage, with its increased costs, is caused in part by irrigation. The demand often exceeds the capacities of water supply plants. Irrigation techniques and equipment that conserve water could lower this seasonal demand appreciably.

Examination of Irrigation Practices

Opportunities to conserve water were identified through a literature search, and through water-use data, on-site observations, and personal interviews at Forts Carson, Bliss, and Lewis. Generally, this work showed that careful positioning of sprinkler equipment could eliminate unnecessary watering. Irrigation often could be done in less time, and during cooler portions of the day. This approach would not harm the turf. Increased emphasis on equipment maintenance and operation would help prevent water distribution problems and water losses through damaged equipment.

On-Site Survey Discussion

Watering Methods. Most problems with existing methods of lawn and turf irrigation involve the general lack of knowledge or guidance about proper watering methods and lack of enforcement of existing watering policies.

Military installations accommodate people from a wide range of climatic and geographic regions -- people who value water differently. Residents accustomed to abundant water supplies and the luxury of lush, green lawns irrigate extensively and tend to continue improper lawn watering habits

Table 2

Water Usage and Utility Costs at a Military Installation, 1975

Month	Water Usage, Thousand Gallons (thousand m^3)	Water Utility Cost, Dollars
January	72,403 (275.13)	35,712.56
February	65,461 (248.75)	32,288.61
March	63,791 (242.41)	31,465.00
April	95,674 (363.56)	47,191.04
May	149,181 (566.89)	73,583.40
June	155,298 (590.13)	76,600.71
July	150,501 (571.90)	74,234.31
August	140,731 (534.78)	69,415.54
September	147,059 (558.82)	72,536.54
October	113,190 (430.12)	55,830.81
November	62,894 (239)	31,022.57
December	59,901 (227.62)	29,546.20
Totals	1,276,084 (4849.12)	629,427.23

developed in regions where water is a cheap and abundant resource. Furthermore, there are few, if any, economic incentives -- i.e., water meters and rate charges -- to limit total installation water use.

Many residents and grounds personnel are not aware of actual lawn and turf moisture requirements, water application and soil infiltration rates, and soil adsorption capacities. All of these are primary considerations in determining the irrigation cycle. Applying too much water too quickly results in puddling and surface water runoff.

Residents tend to overwater to prevent having to pay for replacing a dry, dead lawn. Yet grasses are naturally resistant to drought and protect themselves by going into dormancy. The foliage turns brown, but the growth tissue survives and can be revived with adequate moisture. This browning is normal and should be acceptable; however, installations often emphasize green lawns, and this can lead to overwatering. Excessive irrigation reduces the overall drought resistance of the turf by causing shallow rooting and, in extreme cases, results in waterlogged conditions and scalding. Overwatered turf is also more subject to weed invasion, diseases, insects, and damage from traffic.

A large amount of water is applied to lawns and turfs during the windiest, hottest part of the day, when evaporation rates are highest. Wind and heat can cause poor water distribution and accelerated evaporation. Sprinklers with high, fine sprays, such as those frequently used by family housing residents, are particularly susceptible to wind and evaporation.

Using water unnecessarily (during periods of rain, for example) and forgetting to turn off water to sprinkler hoses are two examples of carelessness by residents or irrigation system operators.

Equipment Operation and Maintenance. Other problems with current irrigation techniques can be attributed to improper operation and maintenance of existing sprinkler systems.

Personnel must periodically reposition portable sprinkler systems or adjust and repair sprinkler heads, including those on permanent or semipermanent systems. Improper sprinkler head adjustment or placement can result in waste if water is allowed to fall on surfaces such as pavement, or if irrigation overlap is too great.

Vandalism and accidental damage to permanent and semipermanent sprinkler systems in commons areas is a problem requiring an intensive maintenance program.

With manual sprinkling systems, each valve controlling the flow of water to the various portions of the system must be turned on and off by hand. These systems are labor-intensive and less efficient than automatic systems, which are operated electrically or hydraulically by remote control valves.

Manually controlled irrigation systems are generally operated by grounds personnel during the typical 8-hour work day, when wind and heat most affect evaporation rates and spray patterns. In addition to a high potential for water waste, there is a greater chance that daytime sprinkler operation will interfere with turf use. Activity on wet turf compacts soil much faster than usual. This reduces the soil infiltration rate and increases the tendency for puddling and runoff.

Contract Requirements. Contract specifications generally do not require the use of water-conserving irrigation techniques. The technical sections of specifications do not provide enough guidance for an effective lawn and turf management program.

On-Site Survey Conclusions

Policies and Practices. Lawn and turf irrigation policies and practices at Army installations should fully support water conservation goals. An evaluation of an activity's lawn watering and turf irrigation program begins with a review of watering policies. After careful examination, policies or practices which hinder water conservation efforts should be revised or eliminated. This review of policies should be conducted by an individual qualified in that field, representing the base Directorate of Engineering and Housing as an in-house expert or outside consultant.

While quantitative specifications are easy to enforce, there should be a latitude for selecting innovative water-conserving equipment or systems. Specifications should measure performance by functional criteria.

When the irrigation plan for an installation is prepared, requirements for water-conserving measures should be included. The in-house or outside expert who prepares the plan is responsible for selecting water conservation

equipment. The manufacturers' specifications for this equipment must indicate that it will meet the installation's needs effectively and economically (see *Economics of Sprinkler Irrigation*).

Specifications for irrigation and mowing requirements are too general. Contracting specifications should be written to emphasize water conservation. Soil maintenance requirements for vegetative plantings must be included. Requirements for soil nutrients, acid/alkaline levels, grading, and density need to be in the maintenance program. The following irrigation performance requirements should be addressed: area locations and acreages; cycles, hours, and methods ot irrigation; special situations involving supplemental irrigation or areas not to be irrigated; and weather influences on irrigation cycles. Inspection, maintenance, and repair of all irrigation equipment also should be included. Mowing, other cultural requirements, and special watering procedures for plantings other than grass and for newly planted or seeded areas should be added to the specifications. Note: soil maintenance, mowing, and irrigation requirements are based on local soil, climate, and vegetation characteristics.

Turf planting and landscaping policies should take into account water conservation. Many installations maintain more turf than required. Areas of maintained turf should be kept to a minimum; this will reduce water and energy usage.

Local turf planting and landscaping policies should be revised not only to restrict the size and number of green, irrigated areas, but also to encourage the use of drought-resistant or native vegetation in renovated lawns or green areas and around all new construction. Rock, brick, wood chips, and other materials should be included as effective landscaping alternatives. TM 5-830-2 and TM 5-830-4 contain good basic information on the initial design, selection, and establishment of vegetation. Installations should evaluate the policy restrictions on, and the feasibility of, using reclaimed wastewaters for irrigating golf courses, roadway medians, and the like. The watering requirement should be eliminated or revised to allow wastewater reuse within acceptable environmental standards. In all cases, plant selection should be based on environmental adaptations to light, temperature, humidity, and soil conditions of the region.

Most Army installations do not have drought contingency plans, although the potential for water shortage, either natural or induced, exists at all installations. Drought contingency plans should be developed to limit nonessential water uses during shortages. An installation should prepare an evaluation of water sources, including their current status and the projected impact ot varying drought conditions. This document should assess water uses for irrigation, and for residential, commercial, industrial, recreational, and other facilities. Lists of essential and nonessential uses should be established and varying levels of water shortage addressed — from a few months to several years. During medium drought conditions, water could be used for maintenance of more expensive shrubs and trees. Under severe or long-term

drought, water should not be used for grass and landscape maintenance. Installations should develop a plan of action for each level of water shortage and be prepared to enforce it. See ER 1110-2-1941 for additional guidance on preparing plans.[12]

Efficient Water Use. Current turf and landscape irrigation practices do not use water efficiently. Several techniques can eliminate waste at little cost to the installation. (Additional information is available from State or university cooperative extension services, local Farm Bureaus, county agricultural departments, or city water utilities.)

Grass need not be watered until the early wilt stage. Wilt or stress is imminent if one leaves footprints when walking across turf.

If most of the turf or lawn looks green and only isolated areas need irrigation, these can be watered by hand. Heat reflected from concrete streets and walkways may cause grass nearby to experience stress before the rest of the turf. These areas should be checked more frequently during hot, dry periods and watered by hand if necessary. Grass in the sun will need more frequent watering than that in the shade.

Water application schedules and automated systems should be adjusted to the timing and amount of rainfall.

Watering should be done in the early morning or evening rather than during the windiest, hottest part of the day. Morning watering is generally preferable; watering in the evening may make the lawn or turf more susceptible to certain diseases because of the extended period of dampness. Watering should be avoided when much traffic is anticipated; irrigation should be done well in advance of parade reviews, graduation ceremonies, football games, and the like.

Apply water according to soil permeability, degree of slope, and type of vegetation (turf, ground cover, trees, or shrubbery). TM 5-630 can be consulted for additional information, including water holding capabilities and infiltration rates for various soil textures.

Increased puddling and surface runoff may indicate soil compaction, or thatch accumulation, particularly if the area is heavily trafficked. To restore the infiltration rate and conserve irrigation water, the turf should be aerated with one of several available techniques. Thatch should be removed as needed to prevent runoff.

If a sprinkler system is used, it should not throw water onto streets, driveways, or walkways.

If the sprinkler system is not automatic, a timer should be set to remind personnel to move or turn off the system after the proper amount of water has been applied.

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[12] Drought Contingency Plans, Engineer Regulation (ER) 1110-2-1941 (DA, Office of the Chief of Engineers, September 1980).

Grass should not be mowed too short. Professional turf managers can find information on mowing heights in TM 5-630.

Equipment. Damaged lawn sprinklers and turf irrigation systems waste water. Mowing around equipment should be done carefully. If the turf is frequently used for military training or activity, removing sprinkler heads between irrigations should be considered.

Operating efficiencies of existing sprinkler equipment and other irrigation systems should be evaluated. This assessment should include: (1) pressure measurements for mains and laterals; (2) application rate; (3) water distribution pattern; and (4) depth of water penetration. The data should be analyzed and changes made accordingly.

Sprinkler heads and nozzles should be cleaned periodically and equipment which wastes water replaced — broken pipe, for example. Heads with different application rates must not be installed on the same circuit because underwatering or overwatering will result.

When considering the installation of a new system or replacement of an existing one, a post should examine automatically controlled systems, soil moisture sensing devices, and special systems, such as drip irrigation. These devices are particularly economical when used for large turfed areas and for new turf which will be irrigated after establishment.

Irrigation system distributors should be consulted for help in developing and designing new systems. This will insure proper equipment design, selection, installation, operation, and maintenance. Table 3 lists techniques for conserving water. (For more information on conservation and system design and operation, see Considerations in Developing an Irrigation Program.)

Emphasis on Conservation. Water conservation should receive more emphasis in energy conservation programs. Existing water conservation informational and educational programs should be reviewed and updated. When there are no programs, they should be developed. Water departments, local and State governments, conservation groups, and public utilities should be consulted for additional information.

Command emphasis on all aspects of water conservation should be insured. Water conservation policies and practices should be encouraged and enforced at all times -- not just when supplies are low.

Considerations in Developing an Irrigation Program

Since water and energy are becoming more scarce and expensive, an irrigation system and program must be selected carefully. The capacities of systems probably will have to be larger to allow more effective use of time and resources. Pressure requirements for effective performance must also receive more attention.

The influences of a particular site are important to effective irrigation. Microenvironmental attributes such as south- and west-facing slopes, shade, concrete areas, and trees may dramatically affect water requirements.

Table 3

Water Conserving Irrigation Techniques

Irrigation Technique	Advantages	Disadvantages
Automatic controllers	1. Eliminates labor required for manual watering. 2. Requires only routine system maintenance and scheduling changes.	1. Periodic adjustments necessary. 2. Expensive initial cost.
Moisture sensing devices	1. Actual turf water requirements can be determined. 2. Use prevents over-watering and leaching of nutrients.	1. Some maintenance required. 2. Moderately expensive.
Drip irrigation	1. Provides maximum beneficial use of available water supplies. 2. Low labor requirement. 3. Chemical additions can be easily applied in irrigation water. 4. No wind effects and lowered evapotranspiration losses.	1. Clogging of emitters or soakers may occur. 2. May cause salt accumulations along fringe of the wetted surface.
Native and other low-water-using plants in landscaping	1. Require little or no irrigation. 2. Require little care and maintenance.	1. Exotic plants generally preferred. 2. Narrow selection in nurseries. 3. May be difficult to establish; there is general lack of knowledge about care. 4. Cost may be somewhat higher because not readily available.
Education	1. Induces voluntary water conservation. 2. Changes wasteful consumer habits. 3. Achieves long-lasting results by setting an example. 4. Insures greater success and acceptance of other water-saving means.	1. Effective program requires coordinated efforts.
Reclaimed wastewater for irrigation	1. Makes maximum use of available water supplies.	1. May cause clogging. 2. Requires continuous monitoring. 3. Potential groundwater contamination. 4. May result in toxic accumulation of metals, salts, or nutrients. 5. May require additional costs for piping, chemical additives, and soil amendments.
Night watering	1. Reduces evaporation effects. 2. Reduces wind drift.	1. May increase disease proneness. 2. Increases labor requirements if irrigation is performed manually.

Of great concern are conditions such as the soil quality after landscaping. At landscaped sites, soil compaction usually reduces infiltration rates, drainage, and aeration. The amount and presence of air and water in soil influence plant growth.

The type of planting must be considered — whether turfgrass, ground cover, trees, or native landscape. Water requirements differ between cultivars and species, and within groups of grasses. Intensity of planting, heavy or light fertilization, cultivation, mowing height and frequency, and traffic affect irrigation requirements. Time of use of the planting as well as the irrigation system must be considered when developing an appropriate program.

Effective Rainfall and Irrigation Frequency

Each day, turf should be checked visually, and the soil moisture tested. The frequency and amount ot irrigation depends on the available water. Figure 5, a diagram of soils at field capacity, clearly shows the amounts of

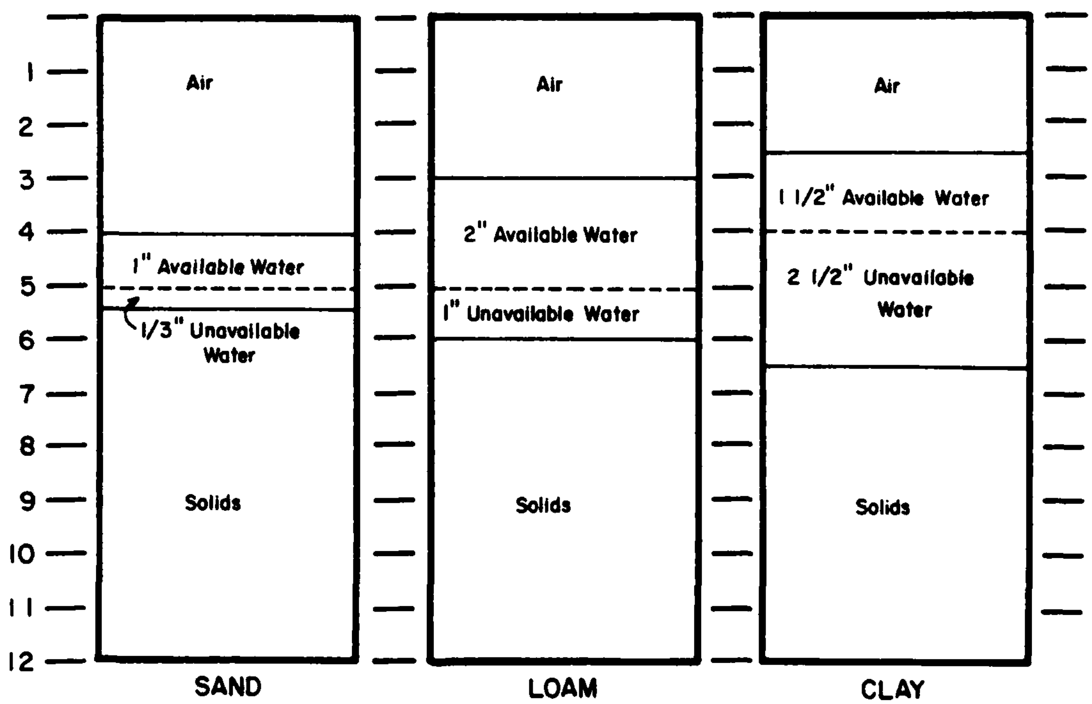

Figure 5. Diagrammatic representation of soils at field capacity. Note amount of soil aeration as this relates to rooting, depth, and volume from which root mass may extract stored water.
(From J. D. Butler and C. M. Feldhake, "Irrigation's Role for Turf and Landscape," in Total Irrigation — Show and Tell [1980 Annual Technical Conference, The Irrigation Association], p 5.)

air, soil, and available and unavailable water in three basic soils. For satisfactory turf surface growth, there must always be adequate soil water in the turfgrass root zone. Frequent, light watering may be necessary during establishment; however, this encourages shallow root growth and should be avoided on established areas. Under favorable conditions, grasses usually have root depths of 1 to 4 ft. Tall fescue, bermuda grass and bahia grass are deep rooted and may go below that zone. Enough water should be added so that the root zone is replenished to a 6- to 8-in. depth.

Frequency of application depends on soil and weather conditions. With average weather, soil holding large amounts of clay normally should be watered weekly. Heavy silt soils or sandy soils with no storage require more frequent irrigation at a slower application rate.

Effective rainfall is the percentage of rain that does not run off, but penetrates the ground surface and is available to plants; about 60 percent of total rainfall is effective. To compute irrigation rates, obtain average monthly rainfall from the U.S. Weather Bureau, multiply by 0.60 and then by 7; divide by the number of days per month to obtain the weekly effective rainfall rate. Subtract this rate from the weekly plant water requirements to obtain the amount of water required in inches. Multiply by 27,154 to get gallons per acre. Adjustments will probably need to be made for factors such as climate and rainfall (see TM 5-630).

Wind direction and velocity affect the design and operation of an irrigation system. For example, watering a given area effectively during 8 to 10 mph winds takes three to four times the number of sprinkler heads needed when winds are 0 to 3 mph. This extra expense can be avoided if watering is done when there is little wind. The direction of prevailing winds may also affect placement of sprinkler heads in the design layout.

Infiltration Rates

Determining the safe intake rate for a given soil is important when planning a sprinkler irrigation system; this can help prevent runoff. Soil surface conditions and physical characteristics control the intake rate; soil aggregation and organic content play significant roles.

Generally, soils take in water at a high rate for about 1 hour. After this, there is a fairly constant rate of intake. The slope of the land influences infiltration by affecting the potential for runoff. Good cover and certain cultural practices increase the intake rate of some soils. For sprinkler design, it is important to know what the condition of the soil will be when the system is installed. Other factors affecting intake rate include quality of the irrigation water, permeability of underlying layers in the soil profile, air entrapment, and presence of a hardpan. Low intake soils generally need light, frequent irrigations. A method for measuring intake rate has been developed by Tovey and Pair.[13]

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[13]C. H. Pair, et al., Sprinkler Irrigation (The Irrigation Association, 1975), pp 67-69.

Quantity of Water

The water required at any given period is a function of available water in the soil, soil water retention characteristics, the water application rate relative to the soil infiltration and percolation rates. Irrigation wetting the soil to a considerable depth promotes deep rooting and healthy turf.

However, excessive amounts of water should be avoided because waterlogged conditions might lower soil oxygen levels, restrict root systems, increase disease development, increase compaction proneness, and reduce turf vigor and quality. Water loss may also occur because of runoff, evaporation, or percolation.

Runoff is wasteful and costly; it can be reduced if irrigation is adjusted to the intiltration rate of the soil. Infiltration rates vary greatly depending on soil texture, structure, amount of compaction, and slope. Special irrigation procedures may be required where low infiltration rates occur.

Water quantity also affects species composition, encouraging some species while discouraging others.

Water Source and Availability

Before an irrigation system is installed, a source of water must be identified. An independent, adequate, high-quality supply of water should be near the center ot the irrigated area. This is especially important for large areas such as golf courses or athletic fields. There should be enough water that the system can operate at full design capacity.

Generally, turfgrass irrigation systems should not be connected to a city water system because city governments may control the times when grass may be irrigated. (In the future, governments will probably increase charges for water and restrict its use even more.)

Common sources of irrigation water are groundwater from wells; perennial flowing rivers or streams; surface water bodies such as ponds, lakes, and reservoirs; and sewage effluent or industrial water. Development costs for wells are high; salt or sand from wells may be troublesome in automatic systems. Large lakes are a particularly dependable water source. Filters will be needed if there are problems with algae, weeds, and other foreign matter in irrigation ponds and lakes. Perennial flowing waters are another source which may be acceptable. The minimum annual flow of the stream must exceed the maximum amount ot water required for irrigation. Prior use rights must also be determined. Again, filters may be required. Nonpotable water should have most ot the solids removed; it should be treated to reduce odors and chlorinated to control bacteria. Significant amounts of nitrogen and phosphorus are usually present.

Water can also be supplied by tank trucks and other portable transport systems. When there is a limited amount of water, artificial lakes or ponds are often used as combination holding tanks and settling basins to maintain an adequate supply. A basin should hold several times the amount of water normally needed.

Water Quality

In many areas, the quality of water used for irrigation is the same as that for the domestic water supply and poses no problems. However, when water is obtained from a source of unknown quality, a water analysis should be performed before any use. A water quality determination usually involves analysis of: (1) total concentration of dissolved constituents; (2) concentration of boron and other potentially toxic elements; (3) relative proportion of sodium to other cations; and (4) bicarbonate concentration.

Total soluble salts are the primary problem in turf irrigation water; but under proper management, highly saline waters can be used. Salinity hazards of irrigation water are presented in Table 4.

Problems with high saline waters can be solved. In areas with good drainage, occasional heavy watering will leach salts below the root zone and prevent salt buildup. Other procedures include planting salt-tolerant turfgrasses such as bermuda grasses, St. Augustine grass, seaside bent grass, or zoysia, or plants which use little water.

High silt or sand content must be avoided because these particles may damage irrigation systems. Settling basins are generally used to handle suspended silt or sand. Mechanical methods or filtering devices may be required in severe cases.

Table 4

Salinity Hazards of Irrigation Water
(From J. D. Butler and C. M. Feldhake, "Irrigation's Role for Turf and Landscape," in Total Irrigation -- Show and Tell [1980 Annual Technical Conference, The Irrigation Association], p 8.)

Hazard	Dissolved Salt, ppm	Content EC* x 10
1. Waters for which no detrimental effects will usually be noticed	500	750
2. Waters which may have detrimental effects on sensitive plants	500-1000	750-1500
3. Waters that may have adverse effects on many plants and require careful management practices	1000-2000	1500-3000
4. Waters that can be used for salt tolerant plants on highly permeable soils with careful management practices, and only occasionally for more sensitive plants	2000-5000	3000-7500

Chemical parameters such as boron toxicity or introduction of industrial waste must be monitored carefully.

Irrigation Methods

An irrigation system is a network of pipes and valves which delivers water to various terminal points for distribution over the soil. Three main methods are available for application of water to turf: overhead or sprinkler irrigation, surface irrigation, and subsurface irrigation. Sprinkler irrigation is the most common. Most systems are permanently installed underground; portable units sometimes are used in establishment of turf areas. Army posts have both portable and permanent units.

Water for sprinklers is distributed through high-pressure (above 60 psi) or low-pressure lines (15 to 30 psi). The high-pressure system is better for watering large areas.

Advantages of sprinkler irrigation include little erosion or puddling, effective coverage of irregular topography, good control of application rates, economical use of water, and adaptability to automation. The main disadvantages are the high installation cost and evaporation losses.

A sprinkler head at the end of a water distribution line spreads water over a given area. The head should evenly disperse fine droplets of water. Uniformity of application depends on spacing, sprinkler head type, water pressure, and wind conditions.

Sprinkler irrigation system controls may be manual or automatic, or a combination called semiautomatic. With manual systems, personnel must move, place, and operate the sprinklers. Common applications are with quick coupling or hose-attached portable sprinklers. The initial cost is lower than for automatic systems. However, the labor expenses and inefficiency of manual systems make long-term operation costs higher.

Automatic systems require no labor for positioning sprinklers. Programmed, timed arrangements control operations and result in increased efficiency.

Perforated pipe or hose is effective for relatively level areas with low water pressure. Many lines may be needed to cover a given area.

Surface irrigation, e.g., flood irrigation, relies on cheap water and level terrain. Water is not conserved, but is distributed and used inefficiently.

Applying water to the turfgrass from beneath without wetting the surface is called subsurface irrigation; there are three approaches: controlling water table, installing porous tile, or using perforated plastic paper. Subsurface irrigation is not practiced at Army installations.

Sprinklers Commonly Used in Residential Areas

Hose, oscillating or wave-type, pulsating, turret, and traveling sprinklers are commonly used in residential areas. Hose sprinklers (Figure 6) release a fine soaking mist through tiny holes. An advantage is that the hose can be shaped to fit areas with uneven shapes. Often called wave-type sprinklers, oscillating sprinklers (Figure 7) are commonly used on small turfgrass areas. A fan of parallel water jets spray through holes of a slowly moving crossbar. The pattern covered is rectangular, characteristic of most lawns.

Pulsating sprinklers (Figure 8) fire bursts of spray as they slowly move back and forth. The spray pattern varies from a narrow wedge to a full circle, according to adjustment. An advantage is that water has time to be absorbed before more is delivered.

Turret sprinklers (Figure 9) have multiple heads with many holes, which give a steady spray. Patterns can be adjusted to form different types and sizes of rectangles. An advantage is that a maximum amount of water can be delivered quickly.

Traveling sprinklers move along a track formed by the outstretched hose (Figure 10). Spray is delivered in a circular pattern with a whirling nozzle. An advantage of this sprinkler is that odd patterns may be traced. Also, the time required to move the sprinkler is decreased.

These residential sprinklers are inexpensive and easy to use. However, if the devices are not in the right location, or if irrigation is done at the wrong time, some areas may be over- or under-watered, or missed entirely. This may also happen if the water pressure is too low. Usually, there is little control over the quantities of water delivered by such sprinklers, so the amount cannot be changed to fit the situation. Most of these sprinklers involve a fair amount of labor; little automation is possible. Wind drift may cause problems in coverage which are difficult to correct.

Sprinkler Systems for Large Turf Areas

Components. Components of sprinkler systems for large turf areas include sprinkler heads and nozzles, controllers, valves, pipes, and fittings.[14] Components discussed here are representative of those for large turf areas; items such as steam sprays, bubbler heads, shrub sprays, and wave sprinklers are not included.

There are two types of sprinkler heads: lawn sprays and rotary sprays. Lawn sprays come in two general categories: pop-up and stationary.

Pop-up lawn sprinklers come in a wide variety of patterns and coverages. Pop-up heads raise the nozzle above the surrounding grass to avoid interference during operation, then drop even with the ground when not in use. Pop-up

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[14]For detailed descriptions of these components, see A. C. Sarsfield, The ABC's of Lawn Sprinkler Systems (Irrigation Technical Services, 1966); J. A. Watkins, Turf Irrigation Manual (Telsco Industries, 1978); C. H. Pair et al., Sprinkler Irrigation (The Irrigation Association, 1975).

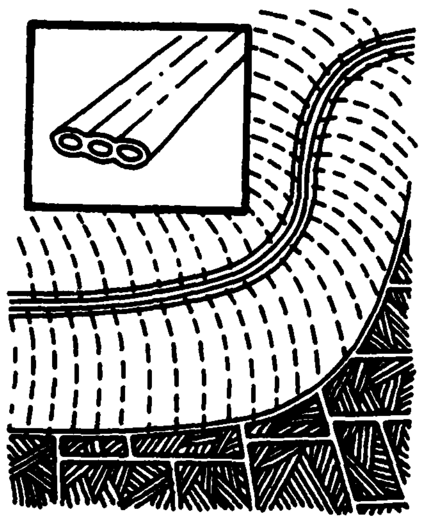

Figure 6. Hose sprinkler.

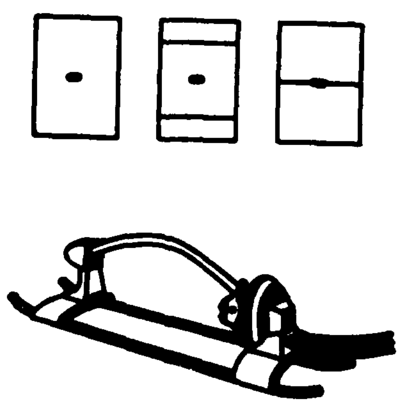

Figure 7. Oscillating sprinkler.

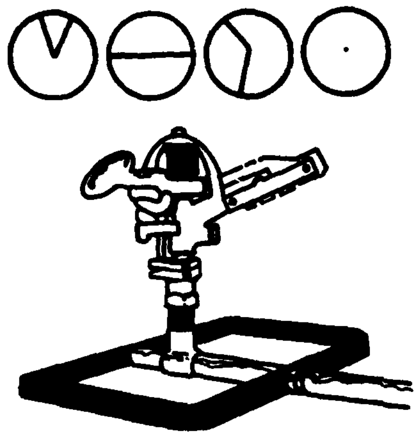

Figure 8. Pulsating sprinkler.

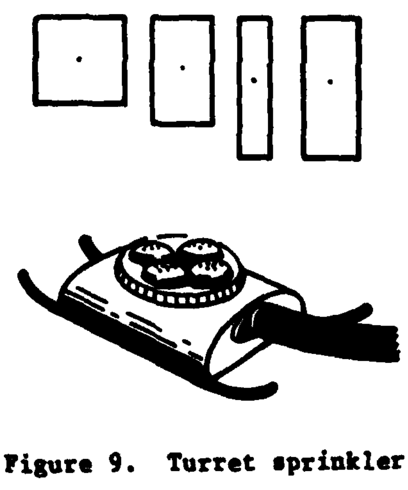

Figure 9. Turret sprinkler.

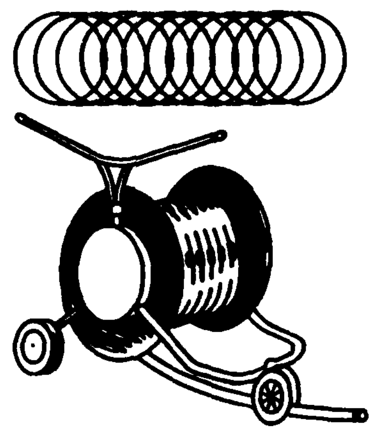

Figure 10. Traveling sprinkler.

lawn heads may be used to water any area requiring uniform coverage and maximum spray control. Less trimming is needed than for stationary heads.

Stationary or fixed heads are the oldest style and are still in wide use today because of their low price. Water under pressure enters through the riser, passes through the nozzle, and is baffled into the desired pattern. Spray nozzles generally project a stream of water in all directions, giving faster watering of an area. There are fewer choices of heads and throws for stationary sprays than for pop-up types. A protective flange surrounds both stationary and pop-up sprays, protecting them from surrounding grass. Fixed spray systems are ideal when installation costs must be as low as possible, and when strict control is needed for small, confined areas. When a post is considering use of stationary heads, the cost of lawn maintenance and appearance of the lawn must be taken into account. Mowing must be done carefully, and nearby grass must be kept trimmed to avoid interference. Strip or line nozzles are available for watering narrow strips. Shrub sprays are similar to fixed sprays, but operate from a small stationary housing above ground level. Stream sprays which disperse water through a serrated nozzle and bubbler sprays which cover small areas are additional modifications of fixed sprays.

Aboveground and pop-up rotary sprinklers generally are used to cover large areas. Rotary sprinkler heads discharge a relatively long, narrow spray pattern which covers a circular area while turning. Part-circle patterns are also available; these cause heavier water application rates. Aboveground types are used with quick-coupling valves or are sometimes permanently mounted on risers. Quick coupler valves are directly connected by risers to live underground pressure lines or aboveground portable lines. Each head is individually controlled and operated manually with a coupler key. The initial installation cost is much lower than for pop-up systems, but labor costs are far higher. Riser mountings can be hazardous to pedestrians. Aboveground rotaries have low precipitation rates and are good for steep slopes. Impact drives are commonly used to produce slow, steady rotation.

Pop-up rotary sprinklers also cover large areas by rotating a stream of water in a circular pattern. These devices are generally used in open areas, where their lesser degree of control is unimportant. Pop-up sprinkler heads are flush with ground level until water pressure lifts them. There is a wide range of coverage patterns, from 35 to 250 ft in diameter. The 70- to 170-ft range is used most often. Heads are generally set in a triangular pattern and spaced at least 60 ft apart. Large pipe sizes and high pressures are necessary to cover large, open turf areas. These sprinklers should be used when there is little wind because the long stream of water drifts easily. Pop-up sprinklers may be powered by several different drive mechanisms -- for example, impact, cam, gear, or ball. There are few maintenance requirements; however, the sprinklers may stop if dirt comes through the line or washes back to the nozzle.

Controllers, especially automatic ones, have great advantages for only a slight additional annual expense. They offer savings in water and labor, provide continuity in watering, and are easy to set up and use. Automatic controllers activate remote control valves. Usually, this is done by electric current or hydraulic pressure, with the power output carried from the controller unit to the valve by underground wires or control tubing. Controllers may be as simple as an on-off switch for one valve, or as sophisticated as computer-operated controls which can time and operate 30 valve circuits in many patterns. Controllers can also be hooked up to soil humidity sensors, and can operate valves to irrigate for a few minutes to an hour per station. Further descriptions of components are in TM 5-630.

Basic Design Considerations. There are many basic design considerations for any irrigation system. The planning and design of a large sprinkler system is complicated and requires experienced specialists. However, the facilities engineer or his designee must review any projects prepared by an outside consultant. Expert assistance is helpful and should be sought for this review. The following discussion provides guidelines for the planning procedures and describes how to check the effectiveness of a finished irrigation plan.[15]

When planning an irrigation system, one must consider the size and shape of area to be irrigated, topography, water supply, soil types, power locations, climatic factors, costs, and special conditions. Also helpful are the area's usage patterns, and the need for and availability of labor. All information should be gathered before work on the design begins.

The contractor should check the following details about the property: dimensions and contours for all planted areas; heights of plantings and relevant special foliage details; locations and sizes of trees, poles, and other obstructions; areas requiring spray protection; presence and measurements of retaining walls or banks; direction of prevailing winds; bordering

[15]For additional information, see A. C. Sarsfield, The ABC's of Lawn Sprinkler Systems (Irrigation Technical Services, 1966); J. H. Turner and E. L. Anderson, Planning for an Irrigation System (American Association for Vocational Materials, 1980); Residential Sprinkler Design Guide (Rain Bird Sprinkler Manufacturing Corp., 1972); J. A. Watkins, Turf Irrigation Manual (Telsco Industries, 1978); C. H. Pair, et al., Sprinkler Irrigation (The Irrigation Association, 1975).

street construction; ditching obstructions; power availability; fence type and height; possible controller locations; and related items.

The following information should be determined about the water supply: water source location, capacity, and types; meter size and location for city water; water main location to determine service line length; static water pressure; size and capacity of existing pump; available power if a new pump is to be installed; suction length and height required if pumping; and any restrictions.

Soil surveys are available in most areas; consult Soil Conservation Service personnel. Note soil profile, profile restrictions, and surface characteristics. Topography influences the strength and quantity of pumping and piping. Climatic conditions and physical features also influence layout and design by affecting depth of piping, drainage needs, and logistics.

After as much information as possible has been gathered, the design process begins with a site or plot plan. This is an accurate map of the area to be irrigated. For larger sites, aerial photography or a survey may be appropriate. Note that with aerial photographs, accuracy deteriorates away from the center of the picture and should be checked with direct tape measurements. For smaller sites, direct measurements are called for. On a freehand sketch, landmarks, buildings, trees, and any other items of interest are measured and marked. Back at a drawing board, an accurate, drawn-to-scale presentation is made showing all dimensions, curves, buildings, trees, planted areas, and other information. All measurements should have been double-checked in the field. If discrepancies appear on the map, go back to the field and remeasure questionable dimensions. Compensation is needed if there is rolling ground and piping is to follow the lay of the land.

Layout of the sprinkler heads can begin after an accurate plot plan has been done. When the sprinkler heads are placed, the troublesome areas are dealt with first. Application rates should be nearly the same for each sprinkler on a circuit. Otherwise, over- or under-watering occurs. When half- or quarter-circle heads are used, flow should be adjusted proportionally. Trees and shrubbery should be watered from each side. The spacing of sprinklers generally provides the overlap needed to get the right amount of water to a given location. For open areas, there are two general spacing patterns: square and triangular. The triangular pattern is more economical and is generally used. For square spacing, coverage is usually 50 percent of spray diameter (in each direction) with average wind conditions. For other prevailing wind conditions, the following adjustments can be made: no wind, 55 percent of diameter; 8 mph wind, 45 percent of diameter. For average wind conditions, triangular spacing results in an equilateral triangle with spacing of 55 percent of spray diameter and a distance of 0.86 times that value between rows of sprinklers. When prevailing winds are calm, use 60 percent of diameter for spacing; for winds of 8 mph, use 50 percent of diameter. It is important that sprinkler spacings not be stretched, but they can be compressed. Before piping layout is started, heads should be adjusted to fit the particular areas.

If the water supply system's physical data are known, its design can be reviewed. Multiply the static pressure by 10 percent to find the maximum meter loss. Using a pressure loss through meters chart (Table 5), find the

Table 5

Pressure Loads Through Water Meters
(From <u>Residential Sprinkler Design Guide</u> [Rain Bird Sprinkler Manufacturing Corp., 1972], p 16.)

	METER SIZE							
Flow G.P.M.	5/8	3/4	1	1 1/2	2	3	4	Flow G.P.M.
6	1.3	.7						6
8	2.3	1.0						8
10	3.7	1.6	.7					10
12	5.1	2.2	.9					12
14	7.2	3.1	1.1					14
16	9.4	4.1	1.4					16
18	12.0	5.2	1.8					18
20	15.0	6.5	2.2	.8				20
22		7.9	2.8	1.0				22
24		9.5	3.4	1.2				24
26		11.2	4.0	1.4				26
28		13.0	4.6	1.6				28
30		15.0	5.3	1.8	.7			30
35			7.4	2.6	1.0			35
40			9.6	3.3	1.3			40
45			12.3	4.1	1.6			45
50			15.0	4.9	1.9	.7		50
60				7.2	2.7	1.0		60
70				9.8	3.7	1.3		70
80				12.8	4.9	1.6	.7	80
90				16.1	6.2	2.0	.8	90
100				20.0	7.8	2.5	.9	100
120					11.3	3.4	1.2	120
140					14.5	4.5	1.6	140
160					20.0	5.8	2.1	160
180						7.2	2.7	180
200						9.0	3.2	200
250						14.0	5.0	250
300						20.0	7.2	300
350							10.0	350
400							13.0	400
450							16.2	450
500							20.0	500

PRESSURE LOSS IN VALVES AND FITTINGS

In terms of Equivalent Length in Feet of Standard Steel Pipe

Pipe Size	Globe Valve	Angle Valve	Sprinkler Angle Valve	Gate Valve	Side Outlet Std. Tee	Run of Std. Tee	Standard Elbow	45° Elbow
1/2	17	9	2	.4	4	1	2	1
3/4	22	12	3	.5	5	2	3	1
1	27	15	4	.6	6	2	3	2
1 1/4	38	18	5	.8	8	3	4	2
1 1/2	45	22	6	1.0	10	3	5	2
2	58	28	7	1.2	12	4	6	3
2 1/2	70	35	9	1.4	14	5	7	3
3	90	45	11	1.8	18	6	8	4
4	120	60	15	2.3	23	7	11	5
6	170	85	20	3.3	33	12	17	8

NOTE: Last flow shown for each meter size is maximum safe flow capacity for meter.

Generally it is not practical to select meter size or flow such that the resultant pressure loss is greater than 10% of the static water pressure at the main service line and in no case flows more than 75% of the maximum safe flow capacity of the meter.

Table 6

Friction Loss in Type 'M' Copper Tube, Standard Iron or Steel Pipe, Asbestos Cement Pipe, and Polyethylene Pipe
(From Residential Sprinkler Design Guide
[Rain Bird Sprinkler Manufacturing Corp., 1972], p 21.)

FRICTION LOSS IN TYPE "M" COPPER TUBE

Pressure Drop Pounds Per Square Inch (psi) Per 100 Feet of Pipe

PIPE SIZE

Flow G.P.M.	1/2"	3/4"	1"	1 1/4"	1 1/2"	2"	2 1/2"	3"
1	.8	.2						
2	3.0	.6						
3	6.1	1.1	.3					
4	10.5	1.9	.6					
5	15.5	2.8	.8	.3				
6		3.9	1.1	.4				
7		5.2	1.5	.6				
8		6.6	1.9	.7	.3			
9		8.2	2.3	.8	.4			
10		9.9	2.8	1.0	.5			
11			3.3	1.2	.6			
12			3.9	1.4	.7			
13			4.5	1.6	.8			
14			5.1	1.8	.9			
15			5.8	2.1	1.0			
16			6.6	2.3	1.1	.3		
17			7.4	2.6	1.2	.3		
18			8.2	2.9	1.4	.4		
19			9.1	3.2	1.5	.4		
20			10.0	3.5	1.6	.5		
22			11.9	4.1	2.0	.5		
24			14.0	4.8	2.3	.6		
25			15.1	5.2	2.5	.7		
26				5.6	2.7	.7		
28				6.4	3.1	.8		
30				7.3	3.5	.9	.3	.14
35				9.6	4.7	1.2	.4	.18
40				12.3	6.0	1.6	.5	.22
45				14.8	7.4	1.9	.7	.28
50					9.0	2.4	.8	.35
60					12.6	3.3	1.1	.46
70					16.8	4.4	1.5	.60
80						5.7	2.0	.83
90						7.1	2.5	1.0
100						8.5	3.0	1.2
120						12.0	4.2	1.7
140					15.9	5.6	2.3	
160						7.1	3.0	
180						8.8	3.7	
200						10.8	4.5	
220						12.8	5.4	
240						15.1	6.3	
280							7.3	

MULTIPLIERS FOR *TYPE L & K COPPER* TUBE ARE

SIZE	L	K
1/2	1.23	1.52
3/4	1.17	1.52
1	1.15	1.33
1 1/4	1.10	1.19
1 1/2	1.08	1.16
2-4	1.06	1.12

Table 6 (Cont'd)

FRICTION LOSS IN STANDARD IRON OR STEEL PIPE

Pressure Drop Pounds Per Square Inch (psi) Per 100 Feet of Pipe

PIPE SIZE

Flow G.P.M.	1/2"	3/4"	1"	1 1/4"	1 1/2"	2"	2 1/2"	3"
1	.91							
2	3.3	.84	.26					
3	6.8	1.8	.55					
4	11.8	3.1	.93	.24	.12			
5	17.8	4.6	1.4	.37	.17			
6	24.9	6.4	2.0	.52	.24			
7		8.5	2.6	.69	.32			
8		10.8	3.3	.88	.42	.12		
9		13.5	4.2	1.1	.52	.15		
10		16.4	5.1	1.3	.63	.19		
11		18.5	6.1	1.6	.75	.22		
12		23.0	7.1	1.9	.88	.26	.11	
13			8.2	2.2	1.0	.30	.13	
14			9.4	2.5	1.2	.35	.15	
15			10.7	2.8	1.3	.40	.17	
16			12.1	3.2	1.5	.45	.19	
17			13.5	3.6	1.7	.50	.21	
18			15.0	4.0	1.9	.56	.23	
19			16.6	4.4	2.1	.61	.25	
20			18.2	4.8	2.3	.67	.28	.10
22			21.8	5.7	2.7	.81	.34	.12
24			25.8	6.7	3.2	.96	.40	.14
25			27.8	7.3	3.4	1.0	.43	.15
26				7.8	3.7	1.1	.46	.16
28				9.0	4.2	1.3	.53	.18
30				10.2	4.8	1.4	.60	.21
35				13.5	6.4	1.9	.80	.28
40				17.3	8.2	2.4	1.0	.35
45				21.6	10.2	3.0	1.3	.44
50				26.2	12.3	3.7	1.6	.54
60					17.3	5.2	2.2	.75
70					23.0	6.9	2.9	1.0
80						8.8	3.7	1.3
90						10.9	4.6	1.6
100						13.2	5.6	1.9
120						18.5	7.8	2.7
140						24.6	10.4	3.6
160							13.3	4.6
180							16.6	5.7
200							20.0	7.0
220							23.9	8.3
240								9.8
260								11.3

Table 6 (Cont'd)

FRICTION LOSS IN ASBESTOS CEMENT PIPE

Pressure Drop Pounds Per Square Inch (psi)
Per 100 Feet of Pipe
AC Pipe Size

Flow GPM	2"	3"	4"
40	1.5	.21	.06
45	1.9	.27	.07
50	2.2	.33	.08
60	3.2	.45	.11
75	4.9	.69	.16
100		1.1	.28
120		1.6	.39
150		2.5	.60
200		4.2	1.0
250		6.4	1.5
300			2.2
350			2.9
400			3.7

FRICTION LOSS IN POLYETHYLENE PIPE

Pressure Drop Pounds Per Square Inch (psi) Per 100 Feet of Pipe

POLYETHYLENE PIPE SIZES

Flow G.P.M.	1/2"	3/4"	1"	1 1/4"	1 1/2"	2"	2 1/2"	3"
2	1.8	.45	.14					
4	6.4	1.6	.50	.13	.07			
6	13.4	3.4	1.1	.28	.13			
8		5.8	1.8	.48	.23	.07		
10		8.8	2.7	.72	.34	.10		
15			5.8	1.5	.72	.22	.09	
20			9.8	2.6	1.2	.36	.15	.06
30				5.5	2.6	.77	.32	.11
40				9.3	4.4	1.3	.54	.19
50				14.1	6.6	2.0	.83	.29
60					9.3	2.8	1.2	.40
70					12.4	3.7	1.6	.54
80						4.7	2.0	.69

Table 7

Friction Loss Through Plastic Pipe
(From Residential Sprinkler Design Guide
[Rain Bird Sprinkler Manufacturing Corp., 1972]. p 22.)

PIPE SIZE

	1/2"			3/4"			1"			1 1/4"			1 1/2"			2"			2 1/2"			3"		
Flow GPM	Class 160	Class 200	Class 315	Class 160	Class 200	Class 315	Class 160	Class 200	Class 315	Class 160	Class 200	Class 315	Class 160	Class 200	Class 315	Class 160	Class 200	Class 315	Class 160	Class 200	Class 315	Class 160	Class 200	Class 315
1	.21	.21		.06	.06		.02	.02																
2	.76	.76	.78	.22	.22		.06	.06																
3	1.61	1.61	1.79	.46	.46		.14	.14		.04	.04													
4	2.74	2.74	2.80	.79	.79	.96	.23	.23		.07	.08		.04	.04										
5	4.14	4.14	4.35	1.19	1.19	1.49	.35	.35		.10	.12		.05	.06										
6	5.80	5.80	5.96	1.67	1.67	2.02	.49	.49	.68	.14	.16		.08	.08										
7	7.83	7.83	8.05	2.26	2.26	2.73	.65	.65	.91	.19	.22		.10	.11										
8	9.87	9.87	10.14	2.84	2.84	3.44	.84	.84	1.14	.24	.28		.13	.14		.04	.05							
9		12.39		3.56	3.56	4.32	1.05	1.05	1.44	.30	.35		.16	.17		.06	.06							
10		14.91		4.29	4.29	5.20	1.27	1.27	1.74	.37	.42	.56	.20	.21		.07	.07		.03	.03				
11				5.25	5.25	6.24	1.55	1.55	2.08	.45	.51	.67	.24	.26		.08	.09		.03	.04				
12				6.20	6.20	7.28	1.83	1.83	2.42	.53	.61	.78	.28	.31		.10	.10		.04	.04				
13				7.16	7.16	8.49	2.12	2.12	2.82	.62	.70	.91	.33	.35		.11	.12		.04	.05				
14				8.11	8.11	9.70	2.40	2.40	3.22	.70	.80	1.04	.37	.40		.13	.13		.05	.05				
15				9.08	9.08	11.10	2.68	2.68	3.67	.78	.89	1.19	.41	.45	.62	.14	.15		.05	.06				
16				10.36	10.36	12.50	3.06	3.06	4.12	.89	1.01	1.34	.47	.51	.70	.16	.17		.06	.07				
17				11.63	11.63	13.90	3.44	3.44	4.63	1.00	1.14	1.50	.53	.58	.79	.18	.19		.07	.08				
18				12.91	12.91	15.44	3.81	3.81	5.14	1.11	1.26	1.66	.58	.64	.87	.20	.22		.07	.08				
19				14.18	14.18		4.19	4.19	5.69	1.22	1.39	1.83	.64	.71	.96	.22	.24		.08	.09				
20				15.46	15.46		4.57	4.57	6.24	1.33	1.51	2.00	.70	.77	1.04	.24	.26	.36	.09	.10		.04	.04	
22							5.35	5.35	7.74	1.56	1.76	2.40	.82	.90	1.24	.28	.30	.42	.11	.12		.04	.05	
24							6.12	6.12	9.24	1.78	2.02	2.82	.94	1.03	1.45	.32	.35	.48	.12	.13		.05	.05	
25							6.90	6.90	9.89	2.01	2.28	3.05	1.06	1.16	1.58	.36	.39	.54	.14	.15		.05	.06	
26							7.82	7.82	10.14	2.28	2.59	3.28	1.20	1.31	1.83	.41	.44	.60	.16	.17		.06	.07	
28							8.75	8.75		2.54	2.89	3.76	1.35	1.47	2.08	.45	.49	.66	.18	.20		.07	.08	
30							9.67	9.67		2.81	3.20	4.26	1.49	1.62	2.22	.50	.54	.74	.20	.22	.30	.08	.09	
35										3.74	4.25	5.09	1.98	2.16	2.94	.67	.72	1.01	.27	.29	.40	.10	.11	
40										4.79	5.45	7.26	2.54	2.76	3.78	.86	.92	1.28	.34	.37	.50	.13	.15	
45											6.77		3.16	3.43	4.68	1.06	1.14	1.60	.42	.45	.63	.16	.18	
50											8.23		3.84	4.17	5.70	1.29	1.39	1.92	.51	.56	.76	.19	.22	.30
60											11.53		5.38	5.84	7.98	1.81	1.95	2.70	.72	.80	1.06	.27	.31	.45
70													7.15		10.62	2.41	2.59	3.58	.96	1.04	1.42	.36	.41	.60
80																3.08	3.32	4.58	1.23	1.32	1.80	.46	.53	.75
90																3.84	4.12	5.70	1.53	1.64	2.24	.58	.66	.90
100																4.66	5.01	6.98	1.85	2.00	2.74	.70	.81	1.04
125																7.04			2.80	3.00	4.14	1.06	1.21	1.58
150																			3.93	4.25		1.48	1.70	2.22
175																			5.22	5.64		1.97	2.25	2.96
200																						2.60	2.90	3.78

corresponding flow in gallons per minute for the given maximum meter loss. From the same chart, obtain the maximum safe flow for the given meter and multiply by 75 percent to get maximum safe flow. This provides loss and flow rate through the meter as boundary conditions not to be exceeded. Find the friction loss in the service line from Tables 6 and 7. This value is in pounds per square inch per 100 feet. Add or subtract the elevation differential to find any loss or gain in pressure. This equals the height change in feet multiplied by 0.43. The result is that working pressure equals static pressure plus or minus pressure changes due to elevation, minus meter loss, minus service line friction loss. For each circuit of sprinkler heads, count the number of each type of head and list the flow rate. Total the amount of flow required, making sure all heads operate at the same pressure. Divide the circuit gallons per minute needed by the gallons per minute available to insure compatibility. The value should be less than or equal to 1.00.

Check sizing of piping for each circuit; if there are many circuits, spot check starting with the longest. Use 20 percent as the pressure variance; from the known sprinkler operating temperature and total circuit length, determine the friction factor defined below:

$$\text{Friction factor} = \frac{0.20 \times \text{operating sprinkler pressure}}{\text{length of circuit in hundreds of feet}} \qquad \text{[Eq 4]}$$

Use the appropriate friction loss chart (Tables 6 or 7) or any appropriate values from a piping or irrigation book to make sure that each section of pipe has a loss of less than the friction factor per 100 ft. It is also recommended that a velocity of 5 ft/sec not be exceeded. It may be helpful to set up a table with the following headings:

(A) FLOW GPM	(B) PIPE SIZE	(C) FRICTION LOSS PSI/100 FT	(D) LENGTH IN FEET	(E) CALCULATION OF LOSS IN PSI (C X D)		(F) PRESSURE LOSS IN PSI
					=	

After the pipes are sized, the total pressure requirements of the circuit should be reviewed. Add the pressure loss of piping, meter, service line, control valve, and elevation. Then add the required sprinkler operating pressure. If this value is less than the static pressure, the design is acceptable.

If pumps or a well system are being included, the friction loss of service line and meter may be omitted if appropriate. The pump should have the necessary capacity and appropriate discharge pressure.

Operation and Maintenance. While the system is being installed, a representative of the facilities engineer should follow construction practices to receive first-hand instructions on all operating phases of the system. The equipment supplier should train the crew members who will run the entire system. The operators should also receive complete written information and operating instructions for the equipment and systems. Decisions must be made about when and how long to irrigate. Start-up and shut-down procedures should be demonstrated to users; then the supplier or contractor should check as users go through the procedures a second time.

For a system to perform as effectively as possible, it must be maintained according to the manufacturer's recommendations. This includes preventive maintenance during the off-season. Appendix C may be helpful in determining schedules for such work.

Application Rate. Application or precipitation rate (PR) is the amount of water applied during a given time period over the irrigated surface area. Normally, the units are inches per hour to the nearest 0.01 in. The method used most often is a formula which includes sprinkler overlap:

$$PR = \frac{\text{GPM (discharge of 1 full sprinkler)} \times 96.3}{\text{sprinkler spacing on the row (ft)} \times \text{row spacing (ft)}} \qquad \text{[Eq 5]}$$

The amount of precipitation may also be checked by measuring the depth of the water that falls in an open can placed on the turf being irrigated. It is imporant to keep sprinklers with similar flows on the same circuit valves. Sprinklers with low precipitation rates should be used on steep slopes or non-porous soil to prevent erosion and water waste. High-precipitation sprinklers are needed for sandy, porous soils in hot, arid climates.

Water Conserving Practices for Irrigation. The amount of water conserved during irrigation depends on the system and the environment.

Systems should be operated according to the following guidelines:

1. Water when there is as little wind and evaporation as possible; early morning is preferable.

2. Check for leaks in the system to prevent unnecessary water loss.

3. Maintain accurate controls to prevent over-watering.

4. Avoid watering areas such as pavements. Valves or sprinkler heads may need to be adjusted.

The following environmental guidelines apply:

1. Analyze plants' water requirements.

2. Check for compaction; aeration may be necessary.

3. Check soil absorbancy; too little or too much clay may require amendments.

4. Check repellency of soil or covering to see if water penetrates to the root zone.

5. Apply only the amount of water needed.

6. Consider plants requiring less water when existing vegetation must be replaced.

Economics of Sprinkler Irrigation

A complete breakdown of irrigation costs should be available to indicate the expenses involved. Initial costs, annual costs on a per acre basis, fixed costs, and operation and maintenance costs on a yearly per acre basis should be included. A true cost analysis would include all direct cash and noncash expenses for irrigation, and the indirect effects of irrigation on other operation expenses.

Water supply costs include expenses for various rights in some areas -- water rights, canal or ditch shares, or storage water rights. Construction expenses for water sources such as wells, ponds, and reservoirs should also be included. Miscellaneous expenses like wastewater disposal facilities may also need to be accounted for.

Conveyance expenses comprise costs of constructing open ditches, closed conduits, bridges, culverts, division boxes, main line piping, valves, and other structures required for water movement to the sprinkler laterals. Distribution system costs cover sprinkler lateral pipe, risers, sprinkler heads, pressure regulators, nozzles, end plugs, and lateral couplings to main lines.

Pumping expenses include the costs of the main pump, bowls, column and all booster pumps, and their installation. Power unit and installation costs and their supply line construction should be considered. Energy may also be a significant expense.

Costs for special equipment should be considered — e.g., soil moisture determination equipment, pipe trailers and hauling equipment, automatic control systems, and any related installation expenses. Other miscellaneous costs may include road or trail construction for equipment delivery, storage buildings, and any other expense which may contribute to the total capital investment. All of the above categories and expenses are the total capital investment.

Annual irrigation costs include fixed costs and yearly operation and maintenance costs. Fixed costs comprise interest on facility expenses, capital loss due to depreciation, taxes, and insurance. Annual operation and maintenance expenses include fuel, electricity, water, labor, equipment repairs, lubrication, taxes, and insurance. Average fuel consumption values should be available from the manufacturers. However, these amounts vary depending on engine condition, maintenance, and manner of use. Power costs depend on the cost of fuel or energy, pump efficiency, and type of power unit. Electric power costs vary inversely with the number of operation hours. Other power modes correspond with horsepower delivered and operational hours.

If the efficiency of a sprinkler system is known, water costs can be fairly accurately determined. Labor costs vary considerably, depending on factors such as the system, amount of automation, amount of piping and equipment to be moved, number of main lines and valves, and irrigation practices.

Drip Irrigation

Definitions and Uses. Drip or trickle irrigation is the frequent, slow application of water through mechanical devices or holes called emitters; these are spaced along the water delivery line. The fundamental concept is to distribute water where it is needed the most — at the plant roots. The water is applied at a rate approximating the soil's loss of water through evapotranspiration. The Army probably would use drip irrigation for trees, shrubbery, and other landscaped areas.

Components. A drip irrigation system consists of emitters, lateral lines, main lines, and control. Emitters control the liquid flow from the lateral into the soil. They are usually placed on the soil's surface, but may be shallowly buried for protection. They range from simple porous wall pipe to complicated mechanical or point source units. Emitter flow rate is usually fixed at 1/2 to 2 gal/hr; 1 gal/hr is most common.

Lateral lines have a small diameter (3/8 to 3/4 in.). They are usually made of plastic. Because flows are low, they may often go long distances.

Main lines are buried; they carry water from the head to the lateral line. Usually made of plastic, they can be of different sizes, depending on the required water flow to the laterals.

The head is the control station for the system. Water distributed to the field is measured (usually by a meter), filtered or screened, and treated. The pressure and timing of application are also regulated. Water for drip irrigation must be cleaner than drinking water; therefore, filters and screens are needed. Injection equipment is also part of the head controls. It is used to inject fertilizer, algicides, and other materials into the lines. Mechanical pressure regulators maintain the design pressure, which depends on the emitter type.

Design. Many factors are involved in the design of a drip irrigation system. Hanson lists the information that must be collected for a landscape project.[16]

1. Project location: physical and political climate, accessibility, restrictions in design, governmental restrictions.

2. Irrigation water: availability/limitations, source, types and/or quality, storage.

3. Climatic data: temperature, wind, rainfall, evapotranspiration.

4. Soil data: qualitative and quantitative analyses; effectiveness of drip irrigation depends on soil texture.

5. Water table data: control of ground water, possible salt contamination.

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[16] R. E. Hanson, "Utilizing Drip Irrigation in Landscape," in Total Irrigation -- Show and Tell (1980 Annual Technical Conference, The Irrigation Association), p 51.

6. Architectural/engineering development: construction impacts, roadways, housing, utilities, construction phasing.

7. Landscape architectural development: routing systems to required areas.

8. Landscape architectural plant selection: proper water amounts at right time ot life cycle for each plant species.

9. Usage/maintenance prospects.

10. Government edicts, codes, plans.

Good drip irrigation design and management attempts to give each plant at least the minimum amount ot water it needs. Uniform emitter discharge determines the uniformity of application. Nonuniform discharge can be caused by pressure differences from friction loss and elevation, clogging, and manufacturing differences. The type of emitter to be used depends on the topography and the crop. A pressure-regulating emitter shculd be installed if the topography is uneven; otherwise, higher operating pressure is called for. For turf, the size ot delivery lines is determined by the length and number of lines and the flow of each. Point-source emitters should be used for trees; the size or lateral lines depends on the number of emitters and the delivery amount per tree. The size of the main line is determined by the number and size or dependent lateral lines.

Screen or sand filters are commonly used. Removing heavy sand loads calls for vortex or other sand separators and settling ponds. Extreme care must be taken to keep out large dirt particles.

If injection systems are needed, the following factors must be considered: method and rate of injection, concentration of the solution and the precision of dilution, tank capacity, and prevention of water supply contamination.

Operation and Maintenance. Drip irrigation offers the greatest control of water, which should be applied slowly. Irrigation must be done often -- i.e., daily or every other day — and each application must last long enough to replace the water consumed by the plants. (Fewer than 15 out of 24 hours should be required.) Tensiometers indicate most accurately when more irrigation is needed.

Maintenance of filters and screens includes periodic cleaning to keep them working perfectly. Faulty emitters can be found through systematic checking. Physical deterioration, mechanical malfunction, and clogging may affect the emitters' discharge. Visual checks for flow should be done weekly. Adjustment valves in the distribution system should be checked periodically and reset if necessary.

Advantages/Disadvantages. Pair, et al., lists several advantages of drip irrigation.[17]

1. Uses available water supplies as efficiently as possible; is unaffected by wind, and is permanent.

2. Offers low labor and relatively low operating costs.

3. Allows irrigation during mechanical operations.

4. Allows application of fertilizer and other chemicals through the system.

5. Improves plant protection from insects and diseases by avoidance of leaf wetting.

6. Limits weed growth because of smaller wetted area.

7. Allows higher efficiency in use of fertilizers; smaller amounts applied result in lower costs.

8. Adapts easily for automatic control.

9. Offers improved infiltration in low intake soils.

10. Uses saline water satisfactorily.

11. Uses greywater easily; this is not a health hazard because there is no human contact.

12. Meets water needs with little stress on plants.

Disadvantages include problems with clogging, salinity buildup in the soil, poor soil distribution, and high installation costs. Costs are comparable to those of sprinkler irrigation.

Water Reuse for Irrigation

Water reuse for irrigation would exploit a potentially valuable resource which is sometimes not used as much as it could be. Rather than dumping wastewater treatment plant effluent into creeks, it could be used as a source of irrigation water for large turf areas such as golf courses or parade grounds. Industrial wastewater treatment plants may be another large source of irrigation water. The quality of both sources should be checked frequently; they should not be used when toxic materials are present or pretreatment is needed to reduce industrial pollutants. A check with local and State pollution control authorities should confirm local rules and regulations regarding health effects. Water rights must be investigated to see if the proposed use is legal. Finally, if use of effluent is permissible, an

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[17] C. H. Pair, et al., Sprinkler Irrigation (The Irrigation Association, 1975), p 510.

economic analysis should be done to compare this approach with the use of potable water. The U.S. Army Environmental Hygiene Agency approves water reuse. CERL's Environmental Division can provide water reuse guidance.

An installation must make sure that treatment plant effluent or nonpotable water from another source reaches a final satisfactory target of bacteriological and chemical quality. Slow-rate land treatment with disinfected secondary effluent has been used for turf, park, and golf course irrigation. Sprinkling has also been done. Generally, domestic sewage requires secondary treatment followed by chlorination before use.

When water reuse for irrigation is being considered, a soil evaluation must be done. This can determine the frequency of irrigation and amount of water needed. A soil evaluation also determines which plant species would be most appropriate for a particular situation.

For reuse of wastewater treatment plant effluent, soil evaluation is concerned with the following characteristics: organic material, soil texture, infiltration rate, percolation rate, topography, and subsurface geology. The presence and quantity of organic material affects fertility of the soil and the amount of water which can be held. Soil texture or particle size is of concern in treating and removing water contaminants. Soil structure affects the permeability of the soil to air and water. Infiltration rate indicates how quickly water can be absorbed into the soil's surface, as well as how much runoff will occur. Topography affects surface runoff and erosion; irrigation is easiest on flat or gently sloping soil. Subsurface geology affects underground water movement. Impermeable layers near the surface can stop percolation and should be avoided. And in fracture areas, for example, percolation may be too rapid, allowing contaminated water to reach groundwater before the contaminants are removed. Excess water in soil may disrupt soil stability in several ways. Montmorillontic clays can cause swelling and heaving following moisture absorption and expansion. Excess water may cause subsurface erosion. The danger from soil creep, slump, or landslides is greatest on hillsides.

Climatic factors affect the use of water for irrigation; they help determine the amount of water that plants need. More water than this may change the species composition and diversity to an exotic or unwanted landscape -- i.e., from desert scrub to moist forest. These factors must be considered since treated sewage effluent represents a constant supply which may not always be needed because of seasonal variations in demand. Effluent storage or disposal mechanisms should be investigated.

When wastewater reuse is planned, installations should select plants that have a high tolerance to salts and to toxics such as boron. Ideally, an agronomist should be on the initial design landscape team. Turfs used on golf courses have been rated for salt tolerance. Generally, bermuda grass is considered the best of the common turfgrasses, followed by zoysia, St. Augustine grass and tall fescue. Next in tolerance level are the creeping bent grasses, followed by annual rye grass and other fescues. Bluegrasses and Colonial bent grass are the least salt-tolerant.

Grasses with a high tolerance to salt are available, but generally they are not used for golf turf. Alkaligrass, tall wheatgrass, western wheatgrass, barley, Rhodes grass, and inland saltgrass are examples.

Turfgrass toxicity to boron is not a great problem. Grasses with rapid accumulation show the earliest injury. Creeping bent grass is most tolerant, followed by perennial rye grass, tall fescue, Kentucky bluegrass, Japanese lawngrass, and bermuda grass.

Trees and shrubs are generally more sensitive to salt and boron damage. Salts cause plant stunting, leaf burn, leaf drop, and stem dieback, and may lower frost resistance. Nothing can be done to prevent boron excess, which can also cause leaf burn.

Nutrients found in wastewater treatment plant effluent include nitrogen, phosphorus, potassium, and most recommended micronutrients. Usually, there is not enough potassium available, so supplemental fertilization may be required. Perennial grasses and legumes generally take major nutrients from the effluent most effectively. It may be necessary to mechanically remove grass clippings from the area to prevent a buildup of elements such as heavy metals and boron.

Limits for pollutants in water used for irrigation vary according to the crop, and legal and public health constraints. A comprehensive chemical and biological analysis should be compared with the recommended guidelines in Table 8, and application made appropriately. The coliform requirement is 200/100 ml for effluent used on parks and golf courses.[18] Salt guidelines are listed in Table 4. CERL Technical Report N-109 contains additional values for irrigation water quality for reuse systems.[19]

In wastewater, nitrogen and ammonia act like fertilizer nitrogen; excessive amounts will cause similar problems.

When dealing with treatment plant effluent or other nonpotable water, the method of irrigation may require solutions to special problems. When sprinkler systems are used, care must be taken to keep out settleable solids, oil, and grease; this can be done either by settling or filtration. Disinfection is required to reduce potential health hazards, especially by aerosols. Installations should also make sure that the components of an irrigation system are not corroded by chlorides and ammonia. High-pressure sprinkler heads should be used; these should have large openings to prevent clogging.

Drip irrigation does not require the high disinfection levels of spray systems; however, there are problems with particulate matter and grease. The small orifices and low flows contribute to clogging. These problems can be solved if the water is run through a rough filter before being used. A jolt of high pressure flow may clear clogged openings, but the operator should be careful not to blow the system apart. Internal blockages caused by slime buildup may be treated by periodic chlorination.

Salt accumulation and the resulting alkalinity increase with time when water is reused; installations must correct these problems. As soil becomes alkaline, many minerals become chemically fixed and unavailable to plants;

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[18] USEPA Land Treatment of Municipal Wastewater, EPA 625/1-81-013 (U.S. Environmental Protection Agency, 1981), pp 4-25.

[19] J. T. Bandy, et al., A Procedure for Evaluating Subpotable Water Reuse Potential of Army Fixed Facilities, Technical Report N-109/ADA111191 (U.S. Army Construction Engineering Research Laboratory, 1981), pp 83-93.

Table 8

Recommended Limits for Pollutants in Reclaimed Water Used for Irrigation
(From Guidelines for Water Reuse, EPA-600/8-80-036
[U.S. Environmental Protection Agency, August 1980], pp 29-30.)

Constituent	Long-Term Use[a] (mg/l)	Short-Term Use[b] (mg/l)	Remarks
Aluminum	5.0	20.0	Can cause non-productivity in acid soils, but soils at pH 5.5 to 8.0 will precipitate the ion and eliminate toxicity.
Arsenic	0.10	2.0	Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than 0.05 mg/l for rice.
Beryllium	0.10	0.5	Toxicity to plants varies widely, ranging from 5 mg/l for kale to 0.5 mg/l for bush beans.
Boron	0.75	2.0	Essential to plant growth, with optimum yields for many obtained at a few-tenths mg/l in nutrient solutions. Toxic to many sensitive plants (e.g., citrus plants) at 1 mg/l.
Cadmium	0.01	0.05	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solution. Conservative limits recommended.
Chromium	0.1	1.0	Not generally recognized as essential growth element. Conservative limits recommended due to lack of knowledge on toxicity to plants.
Cobalt	0.05	5.0	Toxic to tomato plants at 0.1 mg/l in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Copper	0.2	5.0	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solution.
Fluoride	1.0	15.0	Inactivated by neutral and alkaline soils.
Iron	5.0	20.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of essential phosphorous and molybdendum.
Lead	5.0	10.0	Can inhibit plant cell growth at very high concentrations.
Lithium	2.5	2.5	Tolerated by most crops at up to 5 mg/l; mobile in soil. Toxic to citrus at low doses -- recommended limits is 0.075 mg/l.
Manganese	0.2	10.0	Toxic to a number of crops at a few-tenths to a few mg/l in acid soils.
Molybdenum	0.01	0.05	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high levels of available molybdenum.

Table 8 (Cont'd)

Nickel	0.2	2.0	Toxic to a number of plants at 0.5 to 1.0 mg/l; reduced toxicity at neutral or alkaline pH.
Selenium	0.02	0.02	Toxic to plants at low concentrations and to livestock if forage is grown in soils with low levels of added selenium.
Tin, Tungsten and Titanium	-	-	Effectively excluded by plants; specific tolerance levels unknown.
Vanadium	0.1	1.0	Toxic to many plants at relatively low concentrations.
Zinc	2.0	10.0	Toxic to many plants at widely varying concentrations; reduced toxicity at increased pH (6 or above) and in fine-textured or organic soils.
pH	4.5-9.0		Most effects of pH on plant growth are indirect (e.g., pH effects on heavy metals, toxicity described above).
Fecal Coliform Density	1,000/100 ml		Irrigation waters at or below this limit should from consumption of raw crops irrigated with the waters.
TDS	500-5,000 mg/l		Below 500 mg/l, no detrimental effects are usually noticed. Between 500 and 1,000 mg/l, TDS in irrigation water can affect sensitive plants. At 1000 to 2000 mg/l, TDS levels can affect many crops, and careful management practices should be followed. Above 2,000 mg/l, water can be used regularly only for tolerant plants on permeable soils.

thus, plants show deficiencies although there is no mineral shortage. Salt buildup also coincides with the compaction effects of increased sodium levels. To maintain the proper environment, the soil can be modified and irrigation controlled. Application of gypsum has helped lower soil pH and reduce high chloride levels. Sulfur addition has also been useful. Frequent soil aeration and heavy application of water contribute to leaching of contaminant salts. Blending effluent with potable water or occasionally using a leaching dose of potable water can help establish healthy turfgrass. Standard safe engineering practices must be followed to avoid cross-connections and backflows.

Public health is a dominant concern when nonpotable water is used — particularly wastewater treatment plant effluent. Biological pathogens must be strictly controlled in areas open to the public. Other health concerns include trace elements, trace organics, nitrates, and groundwater. A strict monitoring program of source water and groundwater should be used to prevent any significant danger. Safety limits and common-sense handling procedures should be followed. Chlorination is recommended to prevent the spread of pathogens. Sprinkler systems should not discharge into open surface waters, which they may contaminate, nor into areas where there are people.

The economics of water reuse determine whether a program will be possible. The value of reused water depends on its constant availability and its costs. These can be categorized into four main areas covering capital, and operation and maintenance expenses: additional treatment expenses, conveyance or distribution costs of effluent, storage costs, and water quality monitoring expenses. Costs of using nonpotable water may include on-site connections, facilities to adjust and monitor quality, piping for dual systems, steps to assure human safety, and changes in conventional operations.

Reuse may be beneficial because it provides a constant, reliable supply of water and a source of nutrients. Even if low- or high-cost freshwater is available, nonpotable water may be better for irrigation when the entire installation's use of water is considered.

Evaluation of Irrigation Systems

Appendix D describes one method of evaluating irrigation systems already operating at Army installations.

4 CONCLUSION

CERL's investigation of irrigation practices at Army installations revealed many opportunities for installations to save water with efficient technologies and operating procedures. Most of the water conservation techniques identified would be equally applicable at installations inside and outside the continental United States under peacetime and mobilization conditions. CERL's work indicates that the following guidelines can help save water:

1. To reduce the amount of water used for irrigation, turfgrasses with high tolerances to local environmental conditions should be selected when natural landscaping is not applicable.

2. Innovative irrigation methods such as drip irrigation, wastewater reuse, and automatic control of watering should be considered when new irrigation systems are installed or existing systems are upgraded.

3. Irrigation equipment should receive regular maintenance to insure satisfactory service and to prevent the waste of water.

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APPENDIX A:

TESTING FOR SOIL TEXTURE

The test discussed below is described by Milne.[20] It is based on the consistency of moist soil, and gauges the response of the material to simple manipulation.

1. Take a small amount of soil (about a tablespoon) and moisten it slightly.

2. Knead the soil with your fingers to make sure that the moisture is well mixed with the soil and that any granules are broken down. The mixture should be firm and not so moist that it is runny. Clay particles may take a little while to become saturated and break down; they will feel grainy until they do.

3. Roll this mass between your palms until a ball is formed. Then roll it into as thin a wire as possible. The sandier the soil is, the harder it will be to form a ball, and any wire you can make will quickly disintegrate. As the percentage of clay increases, the more easily the wire keeps its shape and the thinner the wire can become without falling apart. With a very high percentage of clay you can roll a very thin wire that can be picked up by one end. When the amount of clay reaches 35 percent or more, a wire 1/4 in. in diameter can be picked up by one end without breaking.

4. Rub the mixture out thinly against your palm. Clay feels slippery and gives the soil a shine when you press down firmly and spread it out. If the soil is sandy it will not shine and will feel gritty. Silt gives soil a greasy quality, but is not plastic as clay is.

Accurately evaluating soil texture is a skill which is acquired with practice. It is helpful to test a number of different soils in order to become acquainted with a variety of textures. Thus, you can establish a relative scale which will help determine the character of any particular soil.

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[20] Murray Milne, Residential Water Reuse, Report No. 46 (California Water Resources Center, September 1979), pp 137-8.

APPENDIX B:

INFILTRATION AND PERCOLATION TESTS

The quick, simple tests for infiltration and percolation described below are discussed by Milne.[21]

Infiltration Testing

Infiltration rates may be classified as follows:

1. Very low: soils with infiltration rates of less than 0.1 in./hr are classified as very low. In this group are soils that are very high in percentage of clay.

2. Low: infiltration rates of 0.1 to 0.5 in./hr are considered low. This group includes soils high in clay, soils low in organic matter, or shallow soils.

3. Medium: rates of infiltration 0.5 to 1.0 in./hr are classified as medium. Most soils in this group are sandy loams and silt loams.

4. High: high rates include soils with infiltration greater than 1.0 in./hr. Deep sands: deep, well-aggregated silt loams, and some virgin black clays are in this group.

The rate of infiltration can be approximated by a simple test. Remove both ends from a large coffee can, or use a similar large, round cylinder. Jam one end into the soil in the area to be tested; remember that the purpose is to estimate how quickly water will enter the surface of undisturbed soil. Make sure that the edge of the can is buried deep enough so that water does not simply seep under the edge and flow out over the soil surface. Fill the can with water to a level of about 6 in. and mark the level on the inside with a grease pencil or laundry marker. After 1 hour, again mark the inside of the can at the water level and measure the amount of drop for comparison with the classification outlined above.

Percolation Testing

A simple test can be done on-site to determine the permeability of the soil. Comparing the test results with Table B1 indicates the permeability class of the soil.

[21] Murray Milne, Residential Water Reuse, Center Report No. 46 (California Water Resources Center, September 1979), pp 141-144.

Table B1

Permeability Class of the Soil*

Permeability Classes	Rate in Inches Per Hour
Very slow	Less than 0.20
Slow	0.20 to 0.63
Moderate	0.63 to 2.0
Rapid	2.0 to 6.3
Very rapid	More than 6.3

*Undisturbed, saturated soil cores under a constant 0.5 in. of water.

1. With hand tools, dig or bore a hole either 12 in. square or 13 to 14 in. in diameter. One hole should be dug about 12 in. deeper than the intended irrigation system. Nearby, dig a second hole about 48 in. deep.

2. Remove any smeared surfaces from the sides of hole to provide infiltrating waters as natural a soil interface as practical. Remove loose material from the bottom of the hole and add 1 or 2 in. of coarse sand or fine gravel to keep the bottom from scouring.

3. Presoak the hole carefully, never filling it with more than about 8 in. of clean water. Do not drop the water into the hole from a distance; ease it in gently. If it is known that the the soil has low shrink-swell potential and that clay content is low (perhaps less than 15 percent), proceed with the test. Otherwise, wait overnight before continuing.

4. Fill the empty hole with clean water to exactly 6 in. above the soil at the bottom ot the hole (do not consider the layer of protective gravel the bottom ot the hole). The level of water can be most easily gauged with a wooden yardstick held vertically in the hole.

5. Wait 1 hour and measure how much the water level in the hole has dropped. If the gravel in the hole is not taken into account, the rate of drop will be faster than actual water absorption. A portion of a 1-in. drop will actually be space occupied by gravel. This effect can be determined in advance by estimating the volume of the gravel and subtracting it from the volume of water absorbed by the soil.

Assume that the hole has 2 in. of gravel in the bottom and 6 in. of water. It is estimated that the volume of the gravel accounts for 40 percent of the volume ot the first inch that the water level drops. Thus, a 2-in. drop is actually only 1.6 in. A number of factors -- including the size and

shape of the gravel, and the shape of the bottom of the hole -- determine the gravel's effect on the rate of drop. Precise estimates are therefore rather complicated; application of the general rule is acceptable for most purposes.

APPENDIX C:

OFF-SEASON CARE*

Preventive maintenance is the simple precaution that can be taken during a period of nonuse to make certain that sprinkler irrigation equipment is ready for use the next season. Every sprinkler system, from pump and power plant to the sprinklers, requires a certain amount of care in handling, storage, and maintenance. Sand, water, wear, and abuse to equipment take their toll and reduce the efficiency of system operation. Preventive maintenance is an off-season job that will repay the time and effort spent doing it.

When any machinery that has ball or roller bearings is stored, the bearings should be covered with a protective coating of lubricant. As weather changes from warm days to cooler nights, moisture will condense from the air on cold surfaces. If the cold bearing surfaces are covered with lubricant, the moisture won't cause rust and pit the bearings.

Small animals winter in partially enclosed, protected areas. There are many of these areas around stored pump, motor, controls, and pipeline which make excellent living quarters. Tape or otherwise cover the entrance to these enclosed areas in the fall and save many hours of cleaning before the next irrigation.

Pumps

When in doubt, call a qualified pump maintenance man.

(1) Preparation for storage.

(a) Make sure all oil- or grease-lubricated bearings are well-covered with lubricant.

(b) Drain water from pump and connecting pipelines to eliminate damage from freezing.

(c) If a packing gland is used, loosen it.

(d) When pump is stopped, make sure it is free of any material that might be carried in the water.

(e) Cover any exposed metal, such as the shaft, with protective lubricant to eliminate corrosion.

(f) Loosen "V" belt or flat belt drive so belts will be under no tension and insert a piece of grease-proof paper between belts and pulley.

(2) Preparation for use.

* The text of this appendix is reproduced by permission from C. H. Pair et al., Sprinkler Irrigation (The Irrigation Association, 1975), pp 445-450.

(a) Tighten packing gland to proper setting.

(b) Check discharge head thoroughly for foreign matter.

(c) Replace oil or grease with proper weight of bearing lubricant.

(d) Pump shaft should turn freely without noticeable dragging. A deep well turbine pump might require some vertical adjustment.

(e) If source of water is a well, check the static level and drawdown in case a deeper pump setting might be required.

Power Plants

When in doubt, call a qualified electrician for electric motors or a qualified mechanic for internal combustion engines.

(1) Electric Motors. Electric motors and controls require very little maintenance. They often get none. The recommended preparation for storage and annual spring checkup will return their cost many times during the life of your equipment.

(a) Preparation for storage:

1. Make sure all bearings are well lubricated.

2. Cover motor to protect against rodents, insects, and dust, but provide ventilation from cover to prevent condensation.

3. Lock control box in "off" position.

4. If control box is exposed to weather, a canvas cover will protect against moisture and dust.

Make these checks and do this maintenance before power is turned on.

(b) Preparation for use:

1. Inspect for rodent and insect invasion over the storage period.

2. Change motor bearing oil. Oil changes are recommended at least once a year. Do not overfill. Overfilling or spilling oil will hasten the need for complete motor cleaning and baking. Remember, motor bearings require a special type ot lubricant.

(a) Oil bath bearings -- drain oil and replace with proper weight, clean oil.

(b) Grease lube bearings -- if grease gun is used, be sure old grease is purged through outlet hole.

3. "Megger" check the control panel, motor, conduits, etc., to determine the condition of current-carrying conductors, motor windings, contactors, etc.

Corrosion can cause poor contact, poor grounding, direct or high resistance shorts. Electricians and pump maintenance men have the equipment to make these checks and determine when the motor needs cleaning, oven drying, revarnishing, and baking.

4. Change oil in reduced voltage starters. Be sure to clean and flush oil pan before refilling.

5. Check and tighten all electrical connections. Connections making poor contact cause overheating. Any connection that has once been overheated should be replaced with new material.

6. Check all controller contact points. Fine sandpaper or a fine file is recommended to clean copper contacts. Badly pitted or burned contacts should be replaced. You should never file silver or silver-plated contacts. Leave contacts clean and dry so dust will not collect.

7. Clean dust and dirt from all moving parts of motor and panel. Use a vacuum or dry, compressed air. Pressure should not exceed 50 psi. There are solvents that may be sprayed directly on oil-soaked windings to remove dirt, grease, or oil.

8. Test all coils and heaters for continuity and shorts. Clean all magnet surfaces. This will help prevent chattering at holding coils.

9. Check for spare fuses of the proper size. A full set of three is recommended. Never overfuse. Replace all three fuses if one of the present ones is found blown. Check for the good ones later. (See your local electric power office when in doubt about proper size.)

10. Operate disconnect switch slowly to check for alignment of blades and clips. Then, open and close the switch several times to clean oxide from contact points. Any time the switch has been left open, operate it several times before leaving it closed because copper oxide can form in a few hours and result in poor contact and overheating. Contacts should be cleaned of all dust and dirt before operating.

11. Before applying power, be sure to operate all moving parts first by hand.

12. Check for proper rotation of motor and pump.

13. Start lubricating the pump turbine shaft at least a week before starting the pump. Regulate the drip gauge to between two and three drops per minute.

(2) Internal Combustion Engines. Dust, dirt, and moisture are the enemies of working machinery. Special preparations must be made to prevent trouble when equipment is stored at the end of the season. Moisture causes serious damage when it gets inside the engine. High humidity can cause moisture to accumulate inside an engine if all openings are not properly sealed. The manufacturer's specific instructions should be followed in preparation for storage and bringing equipment out of storage. If manufacturer's instructions are not available, the following procedures will pay dividends in extending

the life of the engine. In addition, it could prevent a breakdown of equipment at a critical time that would cause severe crop damage.

(a) Preparation for storage:

1. Run engine to thoroughly warm up oil in the crankcase.

2. Stop engine and drain crankcase oil.

3. Replace drain plug and refill crankcase with highgrade engine oil.

4. Start engine -- and run slowly for 2 minutes to complete oil distribution on all surfaces.

5. Stop engine -- remove all spark plugs.

6. Pour 2 ounces of engine oil into each spark plug hole.

7. With ignition switch off, crank engine for several revolutions to distribute this oil over the cylinder walls and valve mechanism.

8. Replace spark plugs.

9. Drain oil from crankcase.

10. Drain cooling system and close drain cocks (including block, water pump, heat exchanger, oil cooler, and radiator).

11. Drain all fuel from tank, lines, and carburetor bowl. Replace all plugs and close drain cock. If LP gas is used, drain vaporizer-regulator (both fuel and water lines).

12. Lubricate all accessories. Seal all openings airtight with weatherproof masking tape. This includes air cleaner inlet, exhaust outlet, and crankcase breather tube.

13. Check oil filler cap, gas tank, and radiator cap.

14. Spray all accessories and electrical equipment with suitable insulating compound.

15. Insert a strip of grease-proof paper under the "V" belt pulley to prevent fan belt from bonding to pulley.

16. Remove battery and store fully charged.

17. If engine is outside, cover with a waterproof covering.

(b) Preparation for use:

1. Remove all tape from openings that have been sealed.

2. Turn on fuel tank shut-off valve.

3. Shut water drain cocks and add coolant.

4. Check oil drain plug — be sure it is tight. Replace oil filter and add correct amount of oil to engine.

5. Remove spark plugs and spray cylinder walls with a light engine oil.

6. Replace spark plugs and crank engine several revolutions by hand to spread oil on cylinder walls.

7. Fill fuel tank.

8. Lubricate all engine accessories.

9. If a distributor is used, clean cap inside and outside. Inspect cap and rotor for cracks. Lubricate distributor sparingly with suitable lubricant. If magneto is used, inspect breaker points for wear and gap, and lubricate rotor.

10. Check all terminals and electrical connections.

11. If oil bath air cleaner is used, clean and fill with correct grade or oil.

12. Start engine, run slowly for a few minutes. Watch oil pressure and if it fails to come up to correct reading, stop engine at once and investigate cause.

13. Check oil level in crankcase. Bring oil level up to proper mark on dipstick.

<u>Sprinkler Heads</u>

(1) Preparing for Storage.

(a) Inspection of all sprinklers at storage time will eliminate delays in starting time for next irrigation season.

(b) Bearing washers should be replaced if there is indication of serious wear.

(c) If damage has occurred to the oscillating arm, the arm should be replaced. The angle of water-contact of the jet with the arm, if not correct, will change the turning characteristics of the sprinkler.

(d) Do not use any lubricant for either storage or operation of sprinkler heads.

(e) Wear of sprinkler nozzles may be checked with proper size drill bit. Some nozzles may not be drilled to the size marked on the nozzle because the orifice style causes a higher discharge and the nozzle is marked for a size that would give this discharge.

Pipelines

(1) Preparation for storage. Drain all pipelines and completely open all valves.

(a) Aluminum tubing:

1. Inspect pipe ends to make certain that no damage has occurred. Ends should be round for best operation. A slightly tapered wooden plug of proper diameter can be used to round out damaged ends.

2. Inspect pipe for corrosion inside pipe. If any is found, consult suppliers for protection methods.

3. Pipe should be stored on inclined racks well above the ground to permit drainage and air circulation.

4. Pipe left in fields during freezing weather should be completely drained. Side roll laterals and other mechanical moves and continuously moving systems should be tied down to prevent wind damage and in extremely cold weather should be broken into short sections to prevent contraction damage.

5. Do not store pipe in the vicinity of acids, caustic or other chemical fumes or dusts.

6. Avoid contact of animal waste on irrigation tubing during storage or in the field.

7. Pipe makes an excellent nesting area for small animals and birds. If such nesting occurs, cleaning of the tubing before use is necessary. Keep pipe away from power lines when you raise it in the air for cleaning.

(b) Couplers and gaskets.

1. Remove gaskets; clean off silt, sand, or other debris; and store in a dry place.

2. Clean couplers with water after the gaskets have been removed to eliminate any foreign matter that might have collected during operation.

(2) Preparation for use.

(a) Reassemble all couplers, installing gaskets, risers, and sprinklers.

(b) Treat corroded pipe.

(c) Check and lubricate all valves according to manufacturer's instructions.

APPENDIX D:

SYSTEM EVALUATION

Evaluation of Operating Systems*

An existing sprinkler system can be evaluated for adequacy of design and operation with a relatively few pieces of equipment and observations of pressures, application rate, depth of water penetration, and crop damage.

Equipment Needed

The following items are generally required:

(1) Pressure gauge (0 to 100 pounds) with pitot tube attachment to measure pressure at the sprinkler nozzle.

(2) Soil auger, shovel, or probe.

(3) Spray gauge cans (quart oil cans or equivalent)

(4) Graduate to measure water caught in spray gauge cans (500 cc capacity graduated to 1 cc)

(5) Tape (100-foot)

(6) Forms for recording data.

General Sprinkler Performance Requirements

In any sprinkler system there are five main factors that should be checked to determine adequacy of design and operation, and as a basis for possible adjustments in operation.

(1) Application Rate. Water should not be applied at a rate faster than the soil will absorb it. However, it should be applied fast enough to prevent excessive evaporation losses.

(2) Depth of Application. The amount of water applied during an irrigation should not be greater at the point of lightest application than can be held by the soil within the root zone of the crop. Greater amounts should be applied only when leaching to remove harmful salts is necessary.

(3) System Capacity. The equipment should be able to replenish the soil moisture of a rate equal to the peak use rate of water by the crop.

(4) Uniformity of Application. Water should be applied as uniformly as practical over the field.

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* The text of this appendix is reproduced by permission from C. H. Pair, et al., Sprinkler Irrigation (The Irrigation Association, 1975), pp 451-456.

(5) Turf Damage. Water must be applied in a way that will not damage the turf physically.

Evaluation Method

(1) Take pressure measurements on main and lateral pipelines.

(2) Make field observation of application rate.

(3) Take water distribution pattern in area being sprinkled.

(4) Determine if irrigation is filling root zone of crop.

(5) Determine if sufficient sprinkler equipment is available.

(6) Check operating procedure used with sprinkler system.

(7) Analyze the data obtained.

(8) Make recommendations for revision of the system or changes in operating procedures, if necessary.

System Operating Characteristics

(1) Pressure Measurement. With the sprinkler system in operation, measure lateral and main line pressures at various points in the system. If a pitot tube attachment is used, pressure may be measured at the nozzle of rotating-head sprinklers. Otherwise, pressure gages should be connected into the pipelines before the water is turned on. Pressure on lateral pipelines should be measured at the first sprinkler from the main line outlet, the high point in the lateral line, and the end sprinkler. Pressures at sprinklers should be close to the manufacturer's recommended operating pressures for the sprinkler used. The pressure should not vary more than ±10% of the nozzle pressure selected as a basis for this lateral design.

Main line pressures should be measured at the pump, at the highest point on the line, and at the point farthest from the pump. Differences in pressures measured on main lines result from elevation difference between the two measurement points and friction loss in the main pipeline. Allowable friction loss in the main line should not exceed an economically practical value.

(2) Application Rates. Observe the rate at which water enters the soil, especially near the end of the longest sprinkler operating period. There should be no movement of water over the surface and the slightest ponding is generally unsatisfactory. If there is water movement over the soil surface, the application rate is too high and sprinkler nozzle size or operating pressure needs reducing.

(3) Water Distribution Pattern. Set out spray gauge cans in a symmetrical pattern across the area to be sprinkled, between four sprinkler heads in a solid set system, or in the area between two settings of a portable lateral. The gauge cans should be on a 5 x 5 foot spacing where the sprinkler spacing

is less than 60 feet apart, and on a 10 x 10 foot rectangular spacing where the sprinklers are over 60 feet apart. The area selected for pattern tests should be typical of the sprinkler area and conducted with several wind conditions.

Run the sprinkler system for the normal length of time for an irrigation. Shut off the system and measure the depth of water caught in the cans. The depth of water caught can be determined by measuring with a thin ruler, or more accurately by use of a graduated cylinder.

The distribution pattern is made by plotting the depth of water caught in each spray gauge can on a scale map of the area.

The distribution pattern is made by plotting the depth of water caught in each spray gauge can on a scale map of the area. It will be necessary to add the water caught from the two or more settings of a portable lateral system to get the full pattern depth in the irrigated area.

(4) Depth of Wetting. Examine the depth of water penetration at several locations in the sprinkler pattern area, using a shovel, probe, or soil auger. Normally this examination should be made one day after irrigation. Water should penetrate a few inches below the root zone depth of the crop. Excess depth of penetration is a waste of irrigation water unless leaching is desired.

(5) Operating Procedure. Determine from the operator the length of time sprinklers operate at each setting and the number of lateral settings per day.

(6) Adequacy of Sprinkler Equipment. Make an inventory of the number of sprinkler lateral settings needed to cover the area to be sprinkled. Also, inventory the number of laterals operating at the same time. By dividing the number of lateral settings by the product of the number of laterals operating at one time and the number of times a lateral is moved each day, the length of time between irrigations can be determined in days.

Analysis of Data and Recommendations

By analyzing the data obtained, the correctness of design and operation of a sprinkler system can be estimated.

If the pressure at the sprinkler nozzles is not within the operating range recommended by the sprinkler manufacturer, water distribution usually is poor. A check with the system designer will determine if the system was originally designed to operate at this pressure. If not designed to operate at the pressure measured, then check the equipment trouble lists and the equipment for trouble in the system components.

If the pressure varies more than ±10 percent from the median pressure measured along a lateral pipeline, the result will be poor water distribution.

To remedy a large loss in pressure without changing pipe size will require a reduction in length of lateral pipeline, or a reduction in the volume of water flowing in the pipe. This is accomplished by removing a

number of sprinklers from the lateral, reducing spacing of sprinklers along the lateral, reducing the pressure at the head of the lateral, or reducing nozzle sizes in the sprinkler head. Also, a larger lateral pipeline might bring the pressure along the sprinkler lateral within the ±10% of design pressure.

Reduce the nozzle size or nozzle pressure to reduce the application rate. Sometimes the sprinkler spacing on the lateral can be increased to reduce the application rate.

Poor water distribution patterns may be improved by the following methods:

(1) Use proper sprinkler nozzle pressure as recommended by the manufacturer.

(2) Change lateral spacing. Lateral spacing should not exceed 65 percent of the diameter of the pattern under no-wind conditions. For 0- to 5-mile/hour wind, lateral spacing should be limited to 60 percent of the wetted diameter and with 5- to 10-mile/hour wind the spacing should be reduced to 50 percent of the wetted diameter or less.

If the time in days for coverage of the sprinkler design area exceeds the allowable irrigation period during the peak use period, then more laterals will be needed to provide for an adequate irrigation of the crop. This may involve a complete revision of the sprinkler system from pump to sprinkler laterals because of the increased water needed.

If an examination of the depth of water penetration shows too much water being applied, the remedy may be to:

(1) Shorten the operating time of the sprinkler lateral, or

(2) Install smaller nozzles in the sprinklers.

If the depth of water penetration shows too little water being applied, the remedy may be to:

(1) Increase the operating time of the sprinkler lateral, or

(2) Install larger nozzles in the sprinklers.

Step 1 may cause further troubles with shortage of laterals preventing a complete coverage of the area to be irrigated in the time allowed by the crop needs and the soil. Step 2 may cause low sprinkler pressure at the nozzles by overloading the pump and motor which wasn't designed to deliver as much water.

METRIC CONVERSION CHART

1 ft = 0.3 m

1 gal = 3.785 L

1 in. = 25.4 mm

1 lb = .4535 kg

1 psi = 6.895×10^3 Pa

$$^\circ C = ^\circ F - \frac{32}{1.8}$$

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